An Architectural Framework for Seamless Hand-off between UMTS and WLAN Network

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by

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I certify that

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This is to certify that the thesis entitled "**An Architectural Framework for Seamless Hand-off between UMTS and WLAN Network**" being submitted by **Maushumi Barooah** to the Department of Computer Science and Engineering, Indian Institute of Technology Guwahati, is a record of bona fide research work under my supervision and is worthy of consideration for the award of the degree of Doctor of Philosophy of the Institute.

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Abstract

In recent years, Cellular wireless technologies like GPRS, UMTS, CDMA and Wireless Local Area Network (WLAN) technologies like IEEE 802.11 have seen a quantum leap in their growth. Cellular technologies can provide data services over a wide area, but with lower data rates. WLAN technologies offer higher data rates, but over smaller areas, popularly known as 'Hot Spots'. The demand for an ubiquitous data service can be fulfilled, if it is possible for the end-user to seamlessly roam between these heterogeneous technologies. In this thesis, a novel architectural framework is proposed consisting of an intra-ISP network called 'Intermediate Switching Network'(ISN) which is fused between UMTS and WLAN networks as well as data (Internet) services for providing seamless mobility without affecting user's activities. The ISN uses MPLS and Multiprotocol-BGP to switch the data traffic between UMTS to IEEE 802.11 networks, as per the movements of the user. The ISN is integrated with the UMTS network at the GGSN-3G and at the Access Point for IEEE 802.11 network respectively. The Mobile Node considered, is a high end device (e.g. PDA or Smart Phone) which is equipped with two interfaces, one for UMTS and the other for WiFi and can use both the interfaces simultaneously. The simulation result shows the improved performance of the ISN based framework over existing schemes.

Most of the traffic in today's networks use the Transmission Control Protocol (TCP) as the transport layer protocol for reliable end-to-end packet delivery. However, TCP considers packet loss to be the result of network congestion which makes it unsuitable for mobile wireless communication, where sporadic and temporary packet losses are usually due to fading, shadowing, hand-off and other radio effects. During the vertical hand-off between different wireless technologies, the problem of end-to-end connection and reliability management for TCP becomes more severe. This thesis also evaluates the performance of TCP over the proposed ISN based framework. The improved TCP scheme uses a cross layer interaction between the network and the transport layer to estimate TCP retransmit timeout and congestion window during handover. Simulation results establishes effectiveness of the proposed scheme.

Ensuring Quality of Service(QoS) for the mobile users during vertical handover between IEEE 802.11 and UMTS is another key requirement for seamless mobility and transfer of existing connections from one network to another. The QoS assurance criteria for existing connections can be affected by fluctuations of data rates when a user moves from the high speed WLAN network to the low speed UMTS network, even in the presence of another WLAN network in its vicinity. This can happen if the alternate WLAN network is highly loaded. Therefore handover from a high speed network to a low speed network should be avoided, whenever possible. The final contribution of this thesis proposes a QoS based handover procedure that prioritizes the existing connection over the new connections, so that rate fluctuations due to handover can be avoided if there exist another WLAN network in the range of the mobile user. Whenever the possibility of handover is detected, a pre-handover bandwidth reservation technique is used to reserve bandwidth at the alternate WLAN networks to avoid QoS degradation. The proposed scheme is implemented in Qualnet network simulator and the performance is analyzed and compared with traditional handover techniques.

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Chapter 1

Introduction

The Mobile communications and wireless networks are developing at a rapid pace. Advanced technologies are emerging in both these disciplines. Recent years have seen a spurt in the growth of wireless network technologies. Wireless communication technologies like Cellular networks and Wireless Local Area Networks (WLAN) have seen advances in technology and usage. From the early cellular networks like Total Access Communication System (TACS) and Nordic Mobile Telephone (NMT) [1], which offered voice services, cellular networks have advanced to networks like *Global System for Mobile Communication* (GSM) [2], *General Packet Radio Service* (GPRS) [3], *Code Division Multiple Access* (CDMA) [4], *Universal Mobile Telecommunications System* (UMTS) [5] which offer both voice services as well as data services over large coverage areas. Similarly, wireless LAN technologies like IEEE 802.11 [6] have developed to offer high data rates, although over smaller coverage areas known as 'Hotspots'.

Therefore, a number of wireless cellular technologies like GSM, GPRS, CDMA, UMTS and Wireless LAN and metropolitan are networks (MAN) technologies like IEEE 802.16, IEEE802.11 are available with variable coverage, bandwidth, and handoff strategies. Wireless LANs (WLAN) are providing the most economical means for Internet access with very limited coverage. They can be deployed in large scale by integrating them in a heterogeneous network architecture, like with the cellular network such as UMTS etc, to provide better network coverage and connectivity. A cellular data network generally provide low speed data (384 Kbps to 2 Mbps [5]) over a large coverage area, while a WLAN provides high speed data (upto 54 Mbps theoretically with IEEE 802.11g [7]) over a geographically small area. The interoperability between WLAN and cellular networks is breaking new heights for optimized business models. While UMTS systems offer large coverage and a rich network infrastructure, WLANs have the potential for high data rates which allows fast web surfing and high-quality video transmission and gaming applications. An integrated network combines the strengths of each resulting in a wide spread system of providing users with ubiquitous data service, ranging from low to high speed in strategic locations. WLANs are available in a wide range of devices, and are now being viewed as the means of an ubiquitous broadband access platform. IEEE 802.11b can provide link speeds of 11 Mbps and application speeds of 5 Mbps, and latest standards such as 802.11a/g provides even higher speeds, which is ideal for Internet-based data access.

Thus, wireless communication of the future will comprise of several heterogeneous networks whose access technologies will vary to a large extent on the network capacity, data rates, bandwidth, power consumption, received signal strength and coverage areas. With their complementary characteristics, it seems natural to integrate these networks to offer overlapping coverage to mobile users, to provide them ubiquitous coverage to achieve anytime, anywhere connectivity. The advances in wireless technologies in combination with the evolution of mobile equipments having multiple network interfaces leads us to the integration of these technologies to enable the mobile user to achieve *'Always Best Connectivity(ABC)'* [8]. The ABC concept allows a mobile user to choose among a host of networks, that best suits its needs and to change when something better becomes available. So in the presence of multiple access technologies, like UMTS and WLAN, the concept is about not only being connected to but also getting the best of world-wide coverage of cellular networks and high bandwidth of WLAN networks irrespective of their mobility and geographic location. With the required quality of service (QoS) considerations, it will be possible to get the best possible data rates to the users at best prices with their choice of the networks.

These overlapping heterogeneous networks can be integrated through a process called vertical handoff. Vertical handoff is the seamless transfer of an ongoing user session between these networks without the user being aware of the switch over [9, 10]. This demands for a seamless transfer of the mobile node to the best available network with no interruption to the on-going data session. Therefore, an efficient vertical handoff decision scheme is required to be designed, that involves a trade-off among several handoff parameters such as network conditions, system performance, application types, power requirements, mobile node conditions, user preferences, security, cost and the quality of service. In a vertical handoff architecture, different networks have overlapped coverage areas, so that users can be under the coverage of various networks, like UMTS and WLAN networks, at the same time to avail the best of each network for data services like accessing the Internet. With the emergence of a variety of mobile data services with variable coverage, bandwidth, handoff strategies and the need for mobile nodes to roam among these networks, vertical handoff in hybrid data networks has attracted tremendous attraction. A typical vertical handover procedure is composed of three main phases: initiation, decision, and execution [9]. During the initiation phase, the mobile node scans for available candidate network for connection which may include several parameters like the supported data rates and QoS parameters. This phase needs to be invoked periodically, since the users are mobile. In the decision phase, the mobile node selects the best network depending on the information obtained during the scanning phase. Finally in the execution phase, the actual handoff procedure takes place.

This thesis deals with the vertical handover strategy between UMTS cellular network and IEEE 802.11 WLAN networks, where the WLAN networks form small overlapping coverage areas under the larger coverage area of the UMTS network. Therefore, a mobile user always remain under the coverage of UMTS network, however the WLAN coverage is not available always.

1.1 Motivation of the Research Work

An integrated wireless system must keep the best features of individual networks, while at the same time, eliminate their weaknesses and drawbacks. It must be able to support for the best network selection based on users service needs so that each user is always connected to the best available network or networks; should have protocols to guarantee seamless inter-system mobility and have mechanisms to ensure high quality security and privacy. Moreover, the architectural design should be scalable that is it should be able to integrate any number of wireless systems. The concept of integrating two or more systems with the view of seamless mobility and optimal performance has been around for quite some time. Many approaches have been proposed in the literature for the same, such as [11–16] and the references therein. However, there are several drawbacks in the existing systems that motivate us to design a new WLAN-UMTS vertical handover architecture.

UMTS and WLAN technologies can be integrated with different strategies. The two most commonly used strategies are internetworking using *tight coupling* and *loose coupling*. In the *tight coupling* approach [17], the WLAN network is integrated as a part of the UMTS network. WLAN network in this case emulates several functionalities of the UMTS network. A specialized WLAN gateway is placed between the UMTS network and the WLAN network, that implements both UMTS and WLAN protocol stack. Using this approach, both the networks share common authentication mechanisms. However, the traffic from the WLAN network passes through the UMTS network which can be a bottleneck in this architecture. In case of the *loose coupling* approach [18–20], the WLAN network gateway is directly connected to the Internet, and there is no direct link to the UMTS network components. The WLAN network traffic does not passes through the UMTS core network, but goes directly through the network. Though the tight coupling approach reduces the handover delay, but the maximal achievable data rate is still limited to the data rate of the UMTS network. In this respect, the loose coupling approach is more preferable than tight coupling approaches.

Most of the existing vertical handoff mechanisms between UMTS and WiFi are based on Mobile IP based architectures [11,21,22]. In this architecture, mobile IP is implemented in mobile nodes and also in the network devices of UMTS and WLAN networks. The seamless handover is based on the IP mobility between UMTS and WLAN networks. Based on the Layer 2 (L2) handover, the mobile IP based approach can be pre-registered [11] and post-registered [22]. However, this approach requires installation of Home Agent(HA) where the mobile users are registered initially that is the home network and Foreign Agent(FA), the current network of association of the mobile users services in both UMTS and WLAN networks. Since the mobile nodes require to send back the registration details to the home network, this approach suffers from packet delay and packet loss. Moreover, the triangular routing is a serious problem in this approach, which introduces unnecessary delay for packet forwarding. Triangular routing occurs because every data packets are routed to the HA first, and the HA then redirect the packets to the FA.

From the above discussion, it can be observed that using loosely coupled approaches based on Mobile IP leads to sub-optimal routing (triangular routing), increased handover latency, end-to-end delay for the packets and packet loss. Tightly coupled approaches reduce handover latency, but limit the data rates of the WiFi network to that of the UMTS network. They also require extra equipment in the form of translation gateways between UMTS and WiFi networks and suffers from triangular routing too. Therefore a handover scheme is required which is seamless, avoids triangular routing, reduces handover latency and minimizes the changes required to the existing UMTS and WiFi networks. All these goals can be achieved if the traffic is switched between the two networks at a point before it enters any of the two networks. In this work, an *'Intermediate Switching Network'* (ISN) is placed between the data services (e.g. Internet) and the UMTS-WiFi networks. The detailed contributions of this thesis has been summarized in the next section.

1.2 Contribution of the Thesis

In this thesis we propose a novel architectural framework for seamless handoff between UMTS and WLAN networks. Contributions of the thesis is summarized as follows.

1.2.1 An Architectural Framework for Seamless Handoff between IEEE 802.11 and UMTS Networks

The first contribution of the thesis proposes a loosely coupled and an intra-ISP based network architecture called *'Intermediate Switching Network'* (ISN) which is fused between UMTS and WLAN networks as well as data services(Internet) for providing seamless mobility without affecting end-users activities. This ISN is based on a 'Mobility Label Based Network' (MLBN) detailed in the IETF Draft by O.Berzin [23, 24]. In the MLBN network, traffic can be switched between any number of networks using 'Multi-protocol Lebel Switching' (MPLS) and 'Multi-protocol Border Gateway Protocol' (MP-BGP). Inside the MLBN, each of the networks connect at 'Label Edge Routers' (LER), which have a 'Mobility Support Function' (MSF) associated with them. The MLBN is used as an 'Intermediate Switching Network', and is integrated with the UMTS and IEEE 802.11 networks in order to facilitate a smooth handover. The mobile node is considered as a high end device (e.g PDA or Smart Phone) which is equipped with two interfaces. One of the interfaces is used for connecting with the UMTS network while the other is used for connecting with the IEEE 802.11 network. The mobile nodes can use both the interfaces simultaneously.

The ISN framework is independent of mobile IP and therefore, eliminates delay and packet losses due to triangular routing, resulting in better performance. The use of ISN allows users to experience higher data rates while in WLAN network and requires minimal changes in the existing systems. The main advantage of this scheme is that it reduces handover delay and eliminates sub-optimal routing that is inherent in the mobility management schemes based on mobile IP.

Simulation results shows that this ISN based integration framework works well with UDP and TCP data traffics. Thus this MPLS and MP-BGP based architecture provides us with an efficient technique for handoff between heterogeneous networks, allows the user with the opportunity to experience better data rates as compared with mobile IP based systems, and minimizes handover latency. Analysis of the above scheme shows that it supports norms of multimedia data service requirements in terms of delay requirement. Thus the proposed ISN-based approach provides an efficient technique for seamless handoff as compared to the mobile-IP based systems.

1.2.2 Evaluation of the End-to-End TCP Performance for Vertical Handover using Intermediate Switching Networks

In recent years, many different kinds of wireless access networks have been deployed and has become inseparable parts of the Internet. TCP, the most widely used transport protocol in the Internet, was originally designed for wired stationery hosts but it faces severe challenges when user moves around in different networks, and therefore, handoff occurs frequently. For reliable end-to-end packet delivery, most of the traffic on the Internet uses TCP. However, TCP considers packet loss to be the result of network congestion which makes it unsuitable for mobile wireless networks, where sporadic and temporary packet losses are usual due to fading, shadowing, hand-off and other radio effects. During the vertical hand-off between different wireless technologies, the problem of end-to-end connection and reliability management for TCP becomes more severe.

In the second contribution of the thesis, we propose a new TCP variant, called ISN-TCP, that handles typical TCP problems like packet reordering, spurious timeouts, packet losses and network under/over utilization for TCP connections during handover. It introduces an additional cross layer at both the mobile node and corresponding node (the other end of the TCP flow), between transport and network layer, which is used to trigger TCP for handover related actions. ISN-TCP requires freezing to maintain the consistency in connection during handover but it introduces extra delay in the network. Freezing delay is also not tolerable for UMTS network.

We work further on this by extending ISN-TCP and proposing an improved TCP variant ISN-TCP-PLUS. This scheme does not require freezing for connection maintenance used by ISN-TCP. ISN-TCP-PLUS improves the performance of TCP significantly during handover by filtering out the duplicate acknowledgements (dAcks) and calculating the retransmit timer (RTT) of the new network on the fly, The proposed scheme uses an approximation in congestion window (CWnd) calculation, similar to the approaches used for equation-based TCP congestion control. Performance of ISN-TCP-PLUS has been analyzed using simulation results and it shows that the proposed variant performs considerably better than conventional wireless profiled TCP (WP-TCP) and ISN-TCP.

1.2.3 Vertical Handover over Intermediate Switching Framework: Assuring Service Quality for Mobile Users

We further strengthen our framework by incorporating QoS into the handover scheme in terms of different QoS parameters. Ensuring the increasing need of users demanding to stay ‘always best connected’ with an economically subscribed high data rates irrespective of their mobility and geographic location is a critical issue. To achieve such flexibility in communication, we should be able to ensure the continuity of connections and the QoS perceived by the users by transferring an ongoing data session from one channel to another. The standard handover scheme based on ‘Received Signal Strength Identifier’ (RSSI) as the handover metric is not adequate for QoS based solutions.

In the third contribution of the thesis, we propose a QoS-based handover scheme between UMTS and WLAN networks based on the ISN framework. A per-node bandwidth reservation is proposed depending on the economic subscription of the mobile nodes with the service provider which is used for possible handover. Further if the QoS for a mobile node degrades, then the handover decision is taken cooperatively by both the mobile node and the its current point of attachment. A pre-handover bandwidth reservation scheme is proposed to reserve bandwidth at alternate connection points to avoid QoS degradation during handover. Further, pre-handover bandwidth reservation helps to prioritize the handover from one WLAN network to another WLAN network over the handover from UMTS to WLAN network. The effectiveness of the proposed scheme is also analyzed using simulation results.

1.3 Organization of the Thesis

The rest of the thesis is organized as follows.

Chapter 2 presents the basics of UMTS and WLAN architecture with a state-of-the-art survey of the seamless handover schemes already proposed in the literature, for vertical handover between UMTS and WLAN networks.

In chapter 3, we propose a novel architectural framework called the ‘Intermediate Switching Network’ (ISN) for seamless handoff between UMTS and WLAN networks. The performance of the proposed framework is analyzed using simulation results and compared with other existing schemes proposed in the literature.

Chapter 4 proposes a new enhanced end-to-end TCP performance algorithm over ISN to handle problems faced by TCP in wireless networks especially during vertical handover for handling packet retransmissions, spurious timeouts and network over/under utilization.

The effectiveness of the proposed TCP enhancement is analyzed using simulation results.

Chapter 5 discusses a QoS-based vertical handover algorithm over the ISN framework, for dynamic bandwidth reservation at different point of attachments for the mobile uses. The effectiveness of the proposed scheme has been analyzed using simulation results through different QoS parameters.

Finally, Chapter 6 concludes the thesis by summarizing the overall contribution of the thesis, with a discussion about possible future works in this direction.

Chapter 2

Background and Related Works

Vertical handover is an essential component of the architecture of the Fourth Generation (4G) heterogeneous wireless networks. Growing consumer demands for access to anywhere and anytime communication services is accelerating the technological development towards the integration of various wireless access technologies called as Fourth Generation (4G) wireless systems [25]. In a typical 4G networking scenario, handsets or mobile terminals are equipped with multiple interfaces, and therefore they will be able to choose the most appropriate access link among the available alternatives. A number of works have been already proposed in the literature for integrating different types of wireless interfaces together as a part of vertical handover. This chapter discusses about the existing works with a brief description of the 4G technological aspects.

2.1 UMTS and WiFi Network Architecture

This section gives a brief introduction about the UMTS and WiFi network architecture.

2.1.1 UMTS Network Architecture

The UMTS network architecture is shown in figure 2.1. The base station is connected with Radio Network Controller (RNC), which is the governing element of UMTS radio access network (UTRAN) and responsible for radio management and controlling the base station. The RNC is connected with Mobile Switching Center (MSC) that is responsible for voice calls, and 3G-GPRS Support Node (GSN-3G) for providing data services in UMTS. The GSN is of two types - service GPRS support node (SGSN), that responsible for authentication and registration purpose, and Gateway GPRS support node (GGSN),

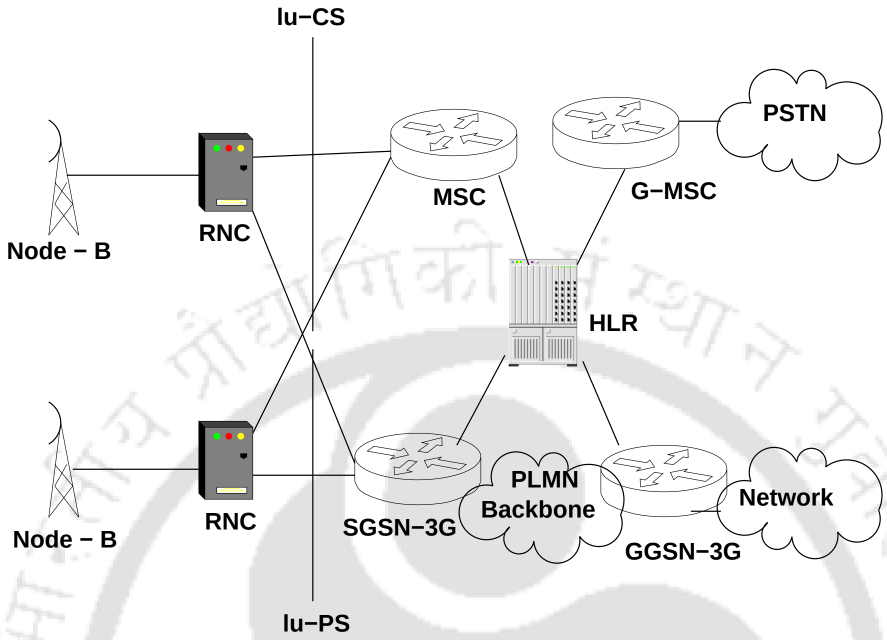

Figure 2.1: 3GPP UMTS Architecture

that acts as the gateway for the public network.

For UMTS-WiFi integration, the GSN is of main interest, as it is responsible for data communication in UMTS network. Whenever a mobile node needs to send packet data to the packet data network (PDN), it has to first establish a 'PDP context' with the GGSN. the GGSN acts as the normal router for the external PDN. Inside the UMTS network, the GGSN is connected to SGSN and the home location register (HLR). GGSN communicates with the SGSN for transferring packets to and from the MN. GGSN depends on the HLR for obtaining any data regarding the MN/Subscriber. Inside the UMTS network, the SGSN is responsible for mobility management. As the GGSN acts as the gateway for the UMTS network and external PDN, so the mobility management functions for handover between two different networks should be integrated at the GGSN.

2.1.2 WiFi Network Architecture

An IEEE 802.11 or WiFi network has mainly two types of stations, namely, the access point (AP) and the mobile node (MN). The basic service set (BSS) is a set of IEEE 802.11 nodes that can communicate with each other directly. There are two types of BSSs, namely, independent BSS and infrastructure BSS. An independent BSS (IBSS) is an ad-hoc network that contains no APs, and as such they can not connect to any other BSS. In

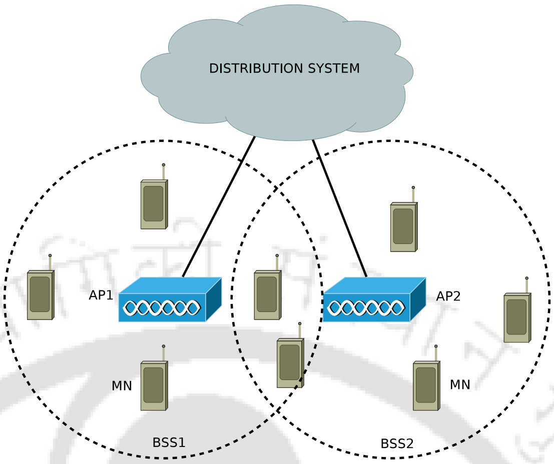

Figure 2.2: IEEE 802.11 Extended Service Set

an infrastructure BSS (iBSS) there is one AP and some MNs. All communications to and from the MNs must go through the AP. MNs in an iBSS can communicate with other MNs in its own BSS and other BSSs as well, through the distribution system. Two or more BSSs may be interconnected through connecting the APs of each BSS by a distribution system. An ESS is a set of one or more interconnected BSSs. An ESS increases both the coverage area and the bandwidth available within the area covered. The distribution system may be connected to other networks so that the stations in the ESS may communicate with other networks. Such an example setup is shown in Fig. 2.2. It can be noted that, to avoid disruption of communication to MNs, different APs should have overlapped coverage area such that communication disruption can be avoided when a MN moves from one BSS to another.

There can be up to fourteen different channels in the 2.4GHz Industrial, Scientific and Medical (ISM) band in which an IEEE 802.11 WLAN operates. Due to the restrictions imposed, not all channels are available in all countries. Channels one to eleven are available in most of the countries. Each channel is of 22MHz bandwidth but spaced only 5MHz apart. As such there can be only three non overlapping channels among the eleven overlapping channels. Although the APs may operate on overlapping channels, it is not desirable to use the overlapping channels in adjacent APs with overlapping coverage area due to the interference and the resulting performance loss. To increase the available bandwidth in an ESS, the APs in an ESS should operate in different non-overlapping channels.

A MN should associate to the AP of a BSS to communicate. A MN associates to an

AP by sending an association request message. The AP, if willing to allow association, replies with an association response message and the MN gets associated to the AP. The association between an AP and a MN is based on signal strength only, where the MN selects the AP with best signal strength, in terms of received signal strength identification (RSSI).

2.2 Multiprotocol Label Switching and Multiprotocol BGP

As discussed in Chapter 1, the proposed vertical handover architecture in this thesis relies on Multiprotocol Label Switching (MPLS) and Multiprotocol BGP (M-BGP). This section gives a brief introduction about these two protocols.

2.2.1 Multiprotocol Label Switching (MPLS)

Multiprotocol Label Switching relies on the use of a label or tag attached to a IP packet, for switching the IP packet through the network. Unlike the various routing protocols used for IP routing, MPLS uses a mapping of (incoming label, incoming interface) to (outgoing label, outgoing interface) for forwarding a packet to the next hop. Each node in the network which supports MPLS, has a list of such mappings. The mappings at each node together form a number of Label Switched Paths between source and destination.

Attaching Labels to Packets

A label is attached to each incoming IP packet. The label is inserted into the IP packet in the form of a shim header. The shim header contains a 20-bit label value along with other bits - 3 experimental bits for grading traffic, end of stack bit and 8 bits as Time To Live (TTL). The shim header is inserted between the IP header and the layer 2 header.

The Label Switched Path (LSP)

In the MPLS network, each of the intermediate nodes with label switching capabilities is called a Label Switching Router (LSR). The LSR maintains a Label Forwarding Information Base (LFIB) which contains the mappings between the incoming label and interface to the outgoing label and interface. As the mappings at each of the LSRs are fixed, the initial label defines the path that the packet takes across the MPLS network. This path is called the Label Switched Path (LSP).

Choosing a suitable LSP

A suitable next hop label needs to be attached to the IP packet such that it can correctly switched to its destination. All the packets that are switched or forwarded in the same way are classified into a Forward Equivalence Class (FEC). The FEC may be a single destination address, a subnetwork address, the source address or even the application. A FEC to Next Hop Label Forwarding Entry (FTN) mapping table can also be used for assigning the correct FEC. The Label Distribution Protocol (LDP) is used for the maintenance of the LSPs.

2.2.2 Multiprotocol BGP

For managing routing across the Internet, routing protocols which handle routing across Autonomous Systems are used. These protocols are known as Exterior Gateway Protocols (EGP). The Border Gateway Protocol is a type of Exterior Gateway Protocol. BGP also used as an Interior Gateway Protocol (IGP) for distributing routing information inside an AS. BGP when used as an IGP is called Interior - BGP (I-BGP). Inside an Autonomous System (AS), routers which can send and receive BGP messages are called BGP Speakers. BGP speakers communicate with each other over TCP connections. BGP Speakers which are connected over a TCP connection are called BGP Peers. While using I-BGP in an AS, all the BGP speakers are connected with each other, forming a complete mesh. The messages used by BGP Speakers to communicate with each other are as follows;

1. Open Message - Used to initiate BGP session between a pair of BGP Speakers. BGP Speakers advertise their capabilities and negotiate various parameters using the Open Message.

2. Update Message - Used for advertising routing information between BGP routers.

3. Notification Message - Error Reporting.

4. Keep Alive Message - Periodic message used to indicate that a BGP session is active.

5. Route-Refresh Message - A request to a BGP router to re-advertise all of the routes in its routing table.

2.3 Vertical Handover between WiFi and UMTS: A Brief Survey

The seamless handoff can be achieved using vertical handoff between UMTS and WLAN networks [26], [27], [28]. UMTS and WLAN technologies can be integrated with different strategies. The two most commonly used strategies are inter-networking using *tight coupling* and *loose coupling* strategies, as discussed next.

- **Tight Coupling:** In the *tight coupling* approach [17], the WLAN network is integrated as a part of UMTS network. WLAN network in this case emulates several functionality of UMTS network. A specialized WLAN gateway called Protocol Translation Gateway (PTGW) responsible for relaying packets from one network to the other is used here. It is placed between UMTS network and WLAN network, that implements both UMTS and WLAN protocol stack. Using this approach, both the networks share common authentication mechanisms. The handover takes place like any normal BSSBSS handover. This method results in faster handover as the PTGW is directly connected to the UMTS network. However, it has a few disadvantages. First, the data traffic will still flow through the UMTS network even after the MN completes handover from UMTS to WLAN. This restricts the data rates to that of the UMTS network. Second, since the PTGW is connected directly with the UMTS network, the PTGW should be a trusted and secure equipment as the internal signaling of the UMTS network is exposed to the WLAN network. Therefore, the traffic from WLAN network passing through the UMTS network can be a bottleneck in this architecture.

- **Loose Coupling:** In case of *loose coupling* approach [18], [19], [20], the WLAN network gateway is directly connected to Internet, and there is no direct link to UMTS network components. The WLAN network traffic does not pass through UMTS core network, but goes directly through the network. Though the tight coupling approach reduces the handover delay, but the maximal achievable data rate is still limited to UMTS network. In this respect, the loose coupling approach is more preferable than tight coupling approaches.

Most of the existing vertical handoff mechanisms between UMTS and WiFi are based on Mobile IP based architectures [21], [29], [30]. In this architecture, mobile IP is implemented in mobile nodes and also in the network devices of UMTS and WLAN. The seamless handover is based on the IP mobility between UMTS and WLAN networks.

Based on the L2 handover, the mobile IP based approach can be pre-registered [29] and post-registered [30]. However, this approach requires installation of home agent and foreign agent services in both UMTS and WLAN networks. Since the mobile nodes requires to send back the registration details to the home network, this approach suffers from packet delay and packet loss. Moreover, the triangulation routing is a serious problem in this approach, which introduces unnecessary delay for packet forwarding.

In [30], the authors proposed a gateway based approach for UMTS-WLAN internetworking. The WLAN and UMTS networks are interconnected using a common gateway. The control signals and the data packets are routed between two networks using the common gateway. The mobile equipment use standard Seamless Mobility (SM) and Global Multimedia Mobility (GMM) to access the UMTS network, and standard IP to connect to WLAN network. Though the gateway approach separates two networks, and also reduces the handover delay, however, the gateway acts as the bottleneck, and hence it performs poorly in high load scenarios. All the packets must have to be routed through the common gateway, and so, this approach is not scalable at all. As a solution, the authors propose an emulator based approach, that use WLAN as a UMTS access stratum. WLAN acts as a cell, a Node-B or a Radio Network Controller (RNC) in UMTS point of view. In fact, this solution use tight coupling to integrate WLAN network with UMTS networks.

In [31], the authors propose a Mobile IPv6 based handover scheme between UMTS and WLAN to reduce handover delay incorporated in Mobile IPv4 based vertical handover. In the proposed algorithm, the first authentication and an optimized gateway is used to reduce handover delay. However, this approach still suffers the problems of mobile IP based architectures, such as triangular routing and signaling delay. Choi et al. [32] uses a pre-registration and pre-authentication based handoff with packet buffering functionality to reduce packet loss during handover. In [33], the authors propose to place an Mobility Anchor (MA) at the boundary between Gateway GPRS Support Node (GGSN) in UMTS network, and protocol data gateway (PDG) for WLAN networks. The MA can enable authentication and session establishment for layer 2 handoff, and can reduce the delay incorporated due to mobile IP signaling. Again the proposed scheme suffers from network bottleneck, as all users should access MA for registration and authentication.

From the above discussion, it can be observed that using loosely coupled approaches based on Mobile IPv4/v6 leads to sub-optimal routing (triangular routing), increased handover latency and end-to-end delay for the packets. Tightly Coupled approaches reduce handover latency, but limit the data rates of the WiFi network to that of the UMTS network. They also require extra equipment in the form of translation gateways between UMTS and WiFi networks and suffers from triangular routing too. Therefore a handover scheme is required which is seamless, avoids triangular routing, reduces handover latency and minimizes the changes required to the existing UMTS and WiFi networks.

2.4 TCP over Vertical Handover Framework

The performance of the TCP protocol over the wired and wireless technologies has been widely studied in the literature [34–41]. To handle the problems of TCP over wireless network, a TCP variant is introduced, called Wireless Profiled TCP (WP-TCP) [42]. WP-TCP uses large CWnd size based on the bandwidth-delay product (BDP). The delay for the BDP is assumed to be sufficiently large to handle channel fading and shadowing. However, increasing CWnd sizes may introduce problems during vertical handover [42]. First, during handover, increasing the maximum window size improves the efficiency in a high BER environment, but degrades the efficiency in a low BER environment. Second, depending on the duplicate ACK threshold, increasing the CWnd may also increase the chances of false fast-retransmits during the vertical handover.

Several works exist in the literature that deal with the TCP performance for the vertical handover [43–51]. However, all of these works are based on mobile IP (MIP) based handover schemes between two different wireless technologies. Most of these works use probing based mechanism after handover, based on the MIP framework, to cope up with the new channel characteristics. However, the MIP based handover faces the problem of triangular routing, and the layer-3 handover operates independently from the link layer handover. This introduces high handover delay in the network, and after the handover, the end-to-end delay increases because of the triangular routing. In [52], the authors have discussed about several TCP variants for a mobile wireless network. Out of them, Split-TCP [53] is a widely accepted variant for the TCP used in the mobile network. Split-TCP proposes to setup multiple proxies along the path of the TCP connections, and the lost packets can be recovered from the most recent last proxy. Thus after handover, only the link properties between the Mobile Node (MN) to the first proxy needs to be updated. However, Split TCP needs to transfer the state information in case of the handover, which increases the handover time. It also violates the end-to-end TCP semantics.

Another variant of the TCP for vertical handover is proposed in [54, 55] that freezes the TCP parameters during handover. This modification of TCP is termed as the freeze-TCP. Freeze-TCP solves the problem of the CWnd dropping by freezing the TCP parameters to avoid unnecessary triggering of the congestion control actions during the handover. After the handover gets complete, TCP resumes its old values of the congestion control parameters, and the normal TCP procedure continues. The problem with freeze-TCP is that, it requires considerable amount of time to adopt to the new link characteristics after the handover gets completed.

The existing TCP variants for the vertical handover, as mentioned earlier, are not applicable for the new handover framework proposed in this thesis, because of the reasons as follows,

1. Most of the existing schemes use the network probing mechanism to find out the round-trip time (RTT) after the handover occurs [43–47]. For the MIP based handover, the network probing is mandatory because of the triangular routing. However, network probing is costly when network traffic does not follow a triangular path.

2. Some of the approaches for the vertical handover use the *"make before break"* strategy [48] where the TCP first adopts the properties of a new connection, and then the layer-3 handover takes place. This approach introduces extra network delay which may not be tolerable for different applications. The new vertical handover framework, proposed in this thesis, is built upon the *"break before make"* strategy where the layer-3 handover occurs after the layer-2 handover gets completed. After the layer-2 handover, the mobility binding updates are used to find out the layer-3 paths. TCP can also adopt to the new environment within this time duration.

3. Zhang *et al.* [49] uses a scheme where the link characteristics information is piggybacked within the IP mobility packets. Similarly, the authors in [50] solve the packet reordering problem using a TCP aware agent at the mobile nodes. These schemes have their limitations on the MIP based handover framework.

2.5 Assuring QoS Over Vertical Hanover Framework

Various handover methods for inter-networking of heterogeneous networks like UMTS and WLAN have been proposed in literature which aim at providing seamless handover from one network to another. There are significant number of works exist on vertical handover in wireless networks [45, 56–64]. All of them uses Received Signal Strength Identifier (RSSI) as the metric for handover initialization decision. RSSI based handover is not a good solution mainly because of two reasons,

- RSSI based handover decision may result in a premature handover between IEEE 802.11 and UMTS [65], even though the achievable data rate from the IEEE 802.11 network for the mobile node is much higher than the one it may get from UMTS network.
- Second in case of heterogeneous networks, different networks may have different values of channel coding loss factor, noise and interference power which makes RSSI incomparable for different wireless technologies.
- Proper load balancing between different network is required to design effective call admission control mechanism.

Thus a better metric is required for making vertical handover decisions. A classification of the state-of-the-art works on vertical handover decisions has been discussed in a recent survey [66]. The survey shows that a major number of works concentrate on conventional Mobile IP and RSSI based handover, while a class of works have designed different handover metrics by combining the QoS parameters as well as other network-centric objectives. In [67] the authors propose a method for signal to interference noise ratio (SINR) based vertical handover scheme for QoS in heterogeneous wireless networks. The proposed inter-system handover algorithm based on SINR can seamlessly transfer a mobile node from one network to another and maintain minimum QoS requirement. The algorithm is triggered when the mobile nodes desired QoS goes below a certain threshold. Though the result shows that SINR based vertical handover provide overall higher throughput with less number of mobile node as compared to RSSI based handover algorithm for different network conditions but it has not been mentioned that how other QoS parameters like delay, jitter etc. can be involved in decision making. In [68], the authors propose an algorithm for Enhanced Mobile IP (E-Mobile IP) handover with less control traffic. The scheme uses link layer information and location information of the neighbors inside every domain of the network. However the scheme does not address issues like the deployment of Mobile IPv6 using link layer information, signaling overhead, packet loss and handover delay. Further, location based schemes are hard to implement in real life. In [69], the authors propose a simple additive weighing based algorithm in which some parameters affecting handover are chosen as decision factor and different weights are assigned to corresponding factors. The candidate network performance is calculated by summing up all the factors along with their corresponding weights. However, the proposed scheme is limited to horizontal handover only, and may not perform well for handover between different wireless technologies.

A vertical handover scheme is proposed in [70] taking SINR and number of bits received at receiver as the handover metric. This scheme increases handover complexity when the mobile node is the sender and appropriate mechanism is required for receiver coordination. Ceken *et al.* [71] propose a vertical handover scheme based on interference characteristics. They have proposed a fuzzy-based system where RSSI, data rate, mobile speed and ambient interference power is taken as input in order to decide handover initialization process. Though the scheme improves both end-user and network performance in terms of handover latency and packet loss compared to RSSI based handover, it is applicable only for the network with low to moderate interference. The scheme is inefficient in terms of load distribution at the time of high network interference [72]. In [73], a set of decision parameters have been taken as the input to a fuzzy controller that initiates handover notification. The scheme takes uncertainty in the decision parameters in consideration while initiating the handover notification. Though the scheme provides better performance compared to other fuzzy based handover decision systems, the uncertainty calculation procedure is time consuming and hard to implement in real network. In [16,74], the authors propose a soft vertical handover scheme where they takes into considerations the network conditions like user mobility, available bandwidth and application type. The proposed algorithm improves the overall performance of the soft handover, however, other QoS parameters like handover delay, packet loss etc. are totally ignored during the design. Lee *et al.* [75] have designed an integration mechanism for IEEE 802.11 and cellular networks for connection and optimal resource management by considering coverage area, available bandwidth and RSSI for achieving seamless handover. In their scheme, handoff to cellular network is performed only if no other data network is found in the vicinity. Their scheme achieves proper load balancing and improved network lifetime by restricting ping-pong effect during handover.

IEEE 802.21 Media Independent Handover (MIH) [76, 77] provides an unified framework for vertical handover between different wireless standards. The MIH framework proposes to use a core network that acts as the intermediation among different technologies. The core network is responsible for handover management and provides three types of services - media-independent event service (MIES) that detects changes in link layer properties, media-independent command service (MICS) to provide a set of command to local and remote MIH users and media-independent information service (MIIS) to provide information about neighboring networks. Several works have been proposed for efficient handover based on MIH services, such as [78, 79] and the references therein. Lin *et al.* provide a vertical handover scheme [80] over MIH scheme based on cross layer scheduling.

However, the scheme does not consider QoS assurance to the existing connections over new connections. Further, the existing handover mechanisms for MIH is based on SINR and do not incorporate any advanced scheme, such as early bandwidth reservations based on network load to provide QoS assurance during handover to nodes which are currently under high speed network.

From the above discussions, the limitations of current state of art works on QoS based vertical handover can be outlined as follows;

1. Most of the works consider SINR as the alternate handover metric to RSSI. However, SINR alone can not guarantee assured service to the end users.

2. The existing frameworks for vertical handover, such as IEEE 802.21 MIH, do no consider QoS assurance to the existing connections over new connections. The existing connections in a high speed network such as IEEE 802.11 WLAN should not be handed over to UMTS if there exists another IEEE 802.11 network in the range. This may happen if the second IEEE 802.11 network is overloaded. This situation can be avoided by designing a mechanism of pre-handoff bandwidth reservation for the existing connections based on the estimation of handover possibility.

3. The admission control policy should distribute traffic load among different available networks based on their QoS assurance criteria. The priority should be given to the existing connections compared to the new connections. New connections should be admitted only after assuring QoS requirement for the existing connections. Also the existing schemes do not balance traffic load among different available technologies based on their QoS assurance criteria.

2.6 Summary

From the above discussion, it can be observed that using loosely coupled approaches based on Mobile IPv4/v6 leads to sub-optimal routing (triangular routing), increased handover latency and end-to-end delay for the packets. Tightly Coupled approaches reduce handover latency, but limit the data rates of the WiFi network to that of the UMTS network. They also require extra equipment in the form of translation gateways between UMTS and WiFi networks and suffers from triangular routing too. Therefore a handover scheme is required which is seamless, avoids triangular routing, reduces handover latency and minimizes the changes required to the existing UMTS and WiFi networks. These goals can be achieved if the traffic is switched between the two networks at a point before it enters any of the two networks. Therefore, a new vertical handover framework is required to be designed to assure seamless mobility in 4G connections. Further, the TCP issues and the QoS provisioning need to be revisited for the new handover framework. The next chapter proposes a new handover framework, that avoids triangular routing, and provides seamless mobility with the help of MPLS and MP-BGP.

Chapter 3

An Architectural Framework for Seamless Handoff between IEEE 802.11 and UMTS Networks

As discussed in previous chapters, a handover scheme is required which is seamless, avoids triangular routing, reduces handover latency and minimizes the changes required to the existing UMTS and WiFi networks. These goals can be achieved if the traffic is switched between the two networks at a point before it enters any of the two networks. In this chapter an Intermediate Switching Network (ISN) is placed between the data services (e.g. Internet) and the UMTS-WiFi networks.This ISN is based on a Mobility Label Based Network (MLBN) detailed in the IETF Draft by O.Berzin [23], [24]. In the MLBN network, traffic can be switched between any number of networks using Multiprotocol Label Switching (MPLS) and Multiprotocol Border Gateway Protocol (MP-BGP). Inside the MLBN, each of the networks connect at Label Edge Routers (LER), which have a Mobility Support Function (MSF) associated with them. The MLBN is used as an Intermediate Switching Network, and is integrated with the UMTS and IEEE 802.11 networks in order to facilitate a smooth handover. The Mobile Node (MN) is considered as a high end device (e.g PDA or Smart Phone) which is equipped with two interfaces. One of the interfaces is used for connecting with the UMTS network while the other is used for connecting with the IEEE 802.11 network. The MNs can use both the interfaces simultaneously.

The rest of the chapter is organized as follows. The proposed framework for integrating UMTS and WLAN network is discussed in Section 3.1. In Section 3.2, the

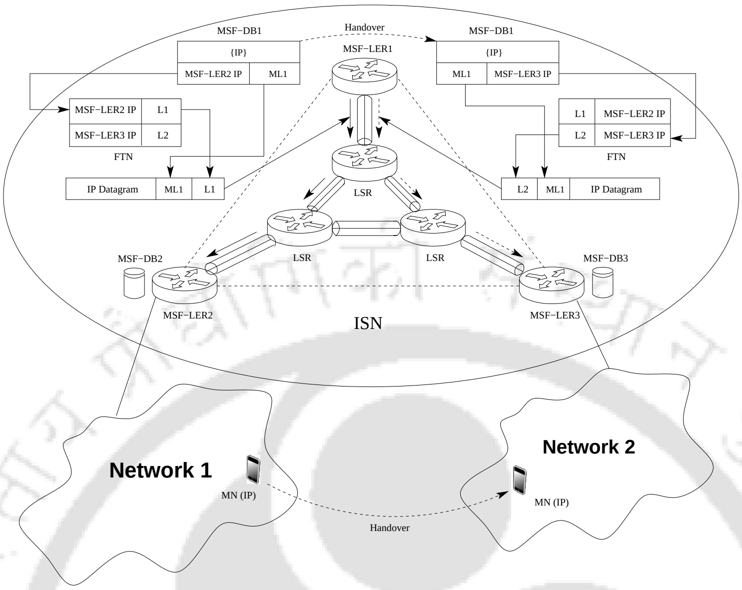

Figure 3.1: Intermediate Switching Network

simulation results are discussed and analyzed. The proposed work is compared with existing schemes in Section 3.3. A brief discussion about handover optimization and authentication is given in section 3.4. Finally, Section 3.5 concludes the chapter.

3.1 Proposed UMTS-WiFi Integration

In the proposed UMTS-WLAN inter-networking architecture, the ISN is placed between the Internet and the UMTS-WiFi network. The integration point of the ISN with UMTS network is the GGSN-3G where as with the IEEE 802.11 network, it is the Access Point (AP).

3.1.1 Intermediate Switching Network

As shown in figure 3.1 the ISN consists of MSF-LERs, which are Label Edge Routers (LER) with a Mobility Support Function (MSF) associated with them. Each of the MSF-LERs is a BGP speaker and a BGP Peer to every other MSF-LER in the ISN, thus forming a complete mesh. The MSF-LERs are connected with each other via Label Switched Paths (LSPs). In figure 3.1, network 1 and network 2 are connected to MSF-LER2 and MSF-LER3 respectively. MSF-LER1 acts as the point at which IP Datagrams enters the ISN. The Mobile Node (MN) initializes the connection in Network 1. A *L2 path* exists between the MN and MSF-LER2.

Registration and Mobility Binding Update

The MN registers with MSF-LER2 using a ICMP Solicitation message. This registration request mainly consists of the pair (MN IP Address, MN L2 Address). After receiving the ICMP Solicitation message from the MN, MSF-LER2 generates a unique *Mobility Label* (ML) and returns it to the MN using an ICMP Advertisement message. This Mobility Label now uniquely identifies the MN and should be used to re-register with the ISN when it moves to a new network. The MSF-LER with which the MN is currently registered is called as the *Home MSF-LER* for that MN. The Home MSF-LER is referred as the point of attachment of the MN with the ISN. After the MSF-LER sends the Mobility Label to the MN, it generates a *Mobility Binding* and distributes it to other MSF-LERs in the ISN. The Mobility Binding mainly consists of the triplet - (Mobility Label, MN IP Address, Home MSF-LER IP Address). The Mobility Binding is distributed to other MSF-LERs using path attribute type 14 of the BGP Update message [23]. At each MSF-LER, there exists a MSF-Database, which is used to store the Mobility Binding along with other information. At the Home MSF-LER of a particular MN, the MSF-Database record for the MN contains Mobility Label, MN IP Address and the MN L2 Address. At other MSF-LERs, the MSF-Database contains the Mobility Label, MN IP Address and Home MSF-LER IP Address of that particular MN (MN L2 Address is not stored at these MSF-LERs).

IP Datagram Delivery and Handover

When IP Datagrams reach MSF-LER1, the MSF functionality performs a look up in its MSF-Database, using the destination IP Address of the IP Datagram. This database look up returns the MSF-Database record containing the Mobility Label assigned for the destination IP Address of the mobile node along with the Home MSF-LER IP Address of the MN. MSF pushes the Mobility Label on to the label stack, and then performs a look up in the FTN at MSF-LER1, using the Home MSF-LER IP Address. This look up in the FTN returns the Forward Equivalence Class(FEC) of the Home MSF-LER IP and thus identifies the LSP to be used to deliver the packet to the Home MSF-LER. MSF then pushes the first label for the identified LSP on to the label stack and forwards the packet to the Home MSF-LER via the LSP. At the Home MSF-LER, the MSF functionality pops the label stack to obtain the Mobility Label. The Mobility Label is then used to perform a look up in the MSF-Database at the Home MSF-LER. This look up returns the L2 address for the MN. MSF uses the L2 address to directly forward the packet to the MN over the L2 path.

When MN moves to Network 2, it re-registers with the ISN (MSF-LER3) using ICMP Solicitation message. However, during this registration, it sends the Mobility Label assigned to it by MSF-LER2 along with the registration request. MSF-LER3 generates a Mobility Binding tuple containing - (Mobility Label, MN IP Address and MSF-LER3 IP Address). This is later distributed to all the other MSF-LERs in the ISN. At each of the other MSF-LERs (including MSF-LER1), the attachment point of the MN to the ISN now changes to MSF-LER3. Now any IP Datagrams coming at MSF-LER1 are forwarded using the LSP going toward MSF-LER3. At MSF-LER3, the L2 address of the MN in Network 2 is used to forward the IP Datagram to the MN.

Any IP Datagrams originating from the MN do not use the MSF functionality and are routed by the normal IP routing procedures.

3.1.2 Integrating ISN and UMTS-WiFi

Figure 3.2 shows the integration of ISN with UMTS and WiFi networks. The integration point of the ISN with UMTS network is the GGSN-3G (GGSN-3G/MSF-LER) where as the integration point for the WiFi network is the Access Point (AP/MSF-LER).

Integration of ISN – UMTS (GGSN-3G/MSF-LER)

The MSF functionality is integrated below the MPLS layer and above the GTP layer in GGSN-3G. At the Mobile Node, MSF operates below the IP layer and above the SNDCP layer. For integrating ISN with UMTS network two things should be taken care of,

1. Establishing a L2 path between GGSN-3G and MN.
2. Mobile Node Registration with GGSN-3G/MSF-LER.

Establishing L2 Path: In a UMTS network, if the MN needs to send/receive data from an External Packet Data Network, a PDP Context needs to be created between the GGSN-3G and the MN. A PDP Context is defined by the IP address assigned to the MN in the UMTS network and the negotiated QoS profile. In this chapter, the negotiated QoS profile is considered as the data rates promised in the UMTS network. There can be multiple PDP Contexts active between the MN and the GGSN-3G at any given time. From the UMTS network point of view, the PDP Context acts as the L2 path between the GGSN-3G and the MN. The creation of a PDP Context is prompted by the kind of traffic that needs to be

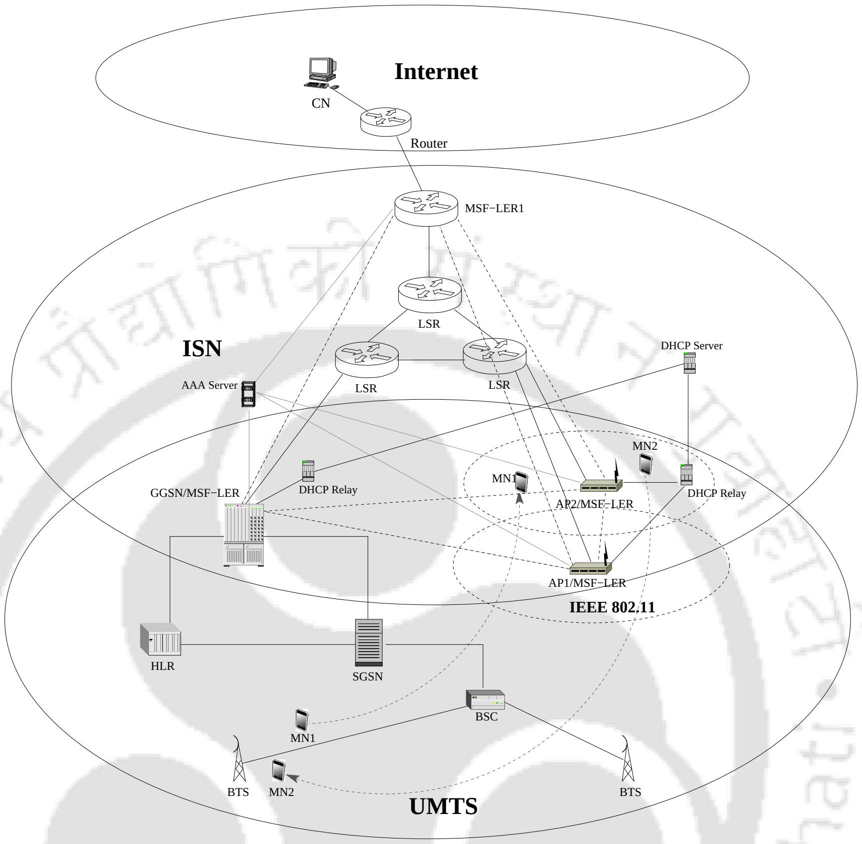

Figure 3.2: Integrating ISN, UMTS and WiFi

sent between the MN and GGSN-3G. In order to register with the GGSN-3G/MSF-LER, ICMP messages are communicated between the MN and GGSN-3G. For communicating ICMP message between MN and GGSN-3G, a default PDP Context with a QoS Profile promising lower data rates is created. This PDP Context is called as ‘*Alternate*’ PDP Context. For the data traffic which is coming from the ISN to the GGSN-3G/MSF-LER, another PDP Context is created with a QoS Profile promising desired data rates and is used to forward the data traffic to the MN. This PDP Context is called as the ‘*Desired*’ PDP Context. The advantage of having multiple PDP contexts facilitate signaling as well as data traffic during handover. So data traffic can also be transferred using the ‘Alternate PDP’ context temporarily, while waiting for the desired QoS profile PDP context creation. The ‘Alternate’ PDP Context can also be used during the handoff from IEEE 802.11 to UMTS network to temporarily forward the packets to the MN, while the ‘Desired’ PDP Context is being created (Section 3.1.4).

Mobile Node Registration with GGSN-3G/MSF-LER: In the UMTS network MN sends registration request to the GGSN-3G/MSF-LER. These requests are sent to the GGSN-3G using ‘Alternate’ PDP Context. At the GGSN-3G/MSF-LER the IP address of the MN and the Mobility Label assigned to it are stored in the MSF-Database. During IP Datagram delivery from ISN to MN, the IP address along with the QoS profile desired for the incoming data traffic, is used by the GGSN-3G/MSF-LER to identify the PDP Context (L2 path) to be used for delivering IP Datagrams to MN.

Integration of ISN – IEEE 802.11 (AP/MSF-LER)

The MSF functionality operates below the MPLS layer and above the LLC layer at APs. At the Mobile Node, MSF operates below the IP layer and above the LLC layer. For integrating ISN with UMTS network two things should be taken care of

1. Establishing a L2 path between AP and MN.
2. Mobile Node Registration with AP/MSF-LER.

Establishing L2 path: For IEEE 802.11 network, the L2 path is provided by the 802.11 MAC layer. Data traffic from the ISN network to the AP/MSF-LER is forwarded using the MAC address of the MN stored in the MSF-Database during MN registration.

Mobile Node Registration with AP/MSF-LER: In the IEEE 802.11 network MN sends registration requests to the AP/MSF-LER. The AP/MSF-LER then assigns a Mobility Label to the MN and stores the Mobility Label along with the IEEE 802.11 MAC Address of the MN, in its MSF-Database. The MN MAC Address being stored, is the MAC Address of the 802.11 interface being used by the Mobile Node while in the IEEE 802.11 network.

3.1.3 Initial Registration with ISN

For seamless vertical handover, the mobile node have to initially register with the ISN using ICMP solicitation and BGP update messages. The initialization procedure is described here.

Initialization in IEEE 802.11 Network

Figure 3.3 shows the initialization procedure when a mobile node is in the IEEE 802.11 network, and tries to register with the ISN. The steps involved in this procedure are as

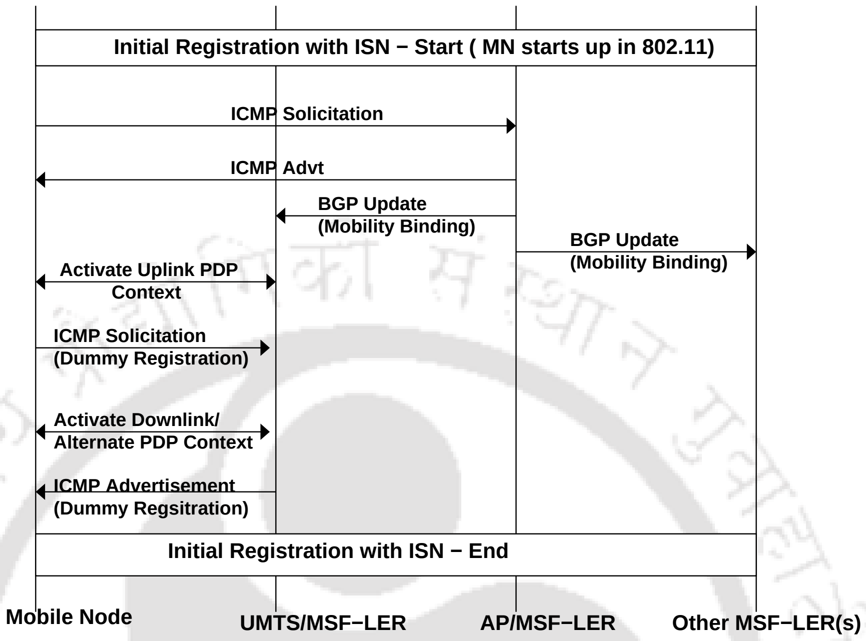

Figure 3.3: Initialization in IEEE 802.11 Network

follows;

1. MN initializes in IEEE 802.11 network and registers with the ISN via AP1/MSF-LER.

2. After completing registration, the MN starts transmitting data traffic from the ISN via the AP1/MSF-LER using the L2 path provided by IEEE 802.11 MAC.

3. Here the registration procedure also contains setting up of the 'Alternate' PDP Context with UMTS network.

   Setting up 'Alternate' PDP Context: Just after the handover from IEEE 802.11 to UMTS, the set up for downlink PDP context requires some time to find out the current network parameters. The 'Alternate' PDP context is used initially. The 'Alternate' PDP Context is used for two purposes - first, it is used for transfer of control messages (which is its primary purpose) and second, it is used to temporarily transfer data traffic to the MN till the time the 'Desired' PDP Context is set up. Once the 'Desired' PDP context set up is over, data traffic follow the path established by 'Desired' PDP context. The process of setting up 'Alternate' PDP context is as follows:

(a) The MN sends a Dummy ICMP Solicitation Registration message to GGSN-3G/MSF-LER. This message does not contain any information pertaining to the registration with the ISN.

(b) The GGSN-3G/MSF-LER responds to this message by simply sending back a Dummy ICMP Advertisement message and does not carry out any registration steps.

(c) The MN ignores the Dummy ICMP Advertisement message sent by the GGSN-3G/MSF-LER.

(d) The sending of Dummy ICMP messages prompts the setting up of Uplink and Downlink PDP Contexts for sending control messages.

(e) The Downlink PDP Context is used by the MSF functionality at the GGSN-3G/MSF-LER as the 'Alternate' PDP Context.

(f) The Uplink and Downlink PDP Context also helps during the handover as the MN does not have to establish PDP Contexts before registering with the GGSN-3G/MSF-LER.

Initialization in UMTS Network

Figure 3.4 shows the initialization procedure when a mobile node is in the UMTS network, and tries to register with the ISN. MN starts up in the UMTS network and prompts the creation of 'Alternate' PDP Context and carries out registration with the ISN (GGSN-3G/MSF-LER). After registering with ISN, MN can send/receive data traffic from ISN. For transmitting data traffic, the 'Desired' PDP Context which acts as the L2 path between GGSN-3G and MN, is created between the MN and GGSN-3G.

3.1.4 Handoff Between UMTS – IEEE 802.11 Networks

The handover from UMTS to IEEE 802.11 and vice versa is initiated by the Mobile Node. The MN monitors for the presence of the 802.11 network periodically. When MN finds a stable IEEE 802.11 network (association with AP possible), it hands over to the IEEE 802.11 network. When in the IEEE 802.11 network, as long as the MN remains in the range of an AP, it remains registered with the ISN through the IEEE 802.11 network. When the MN moves out of range of the IEEE 802.11 network, it initiates the handover to the UMTS network. The handover scenarios considered here are as follows,

- Handover from UMTS to IEEE 802.11 – The Mobile Node is connected in the UMTS network and roams into the coverage area of IEEE 802.11 network.

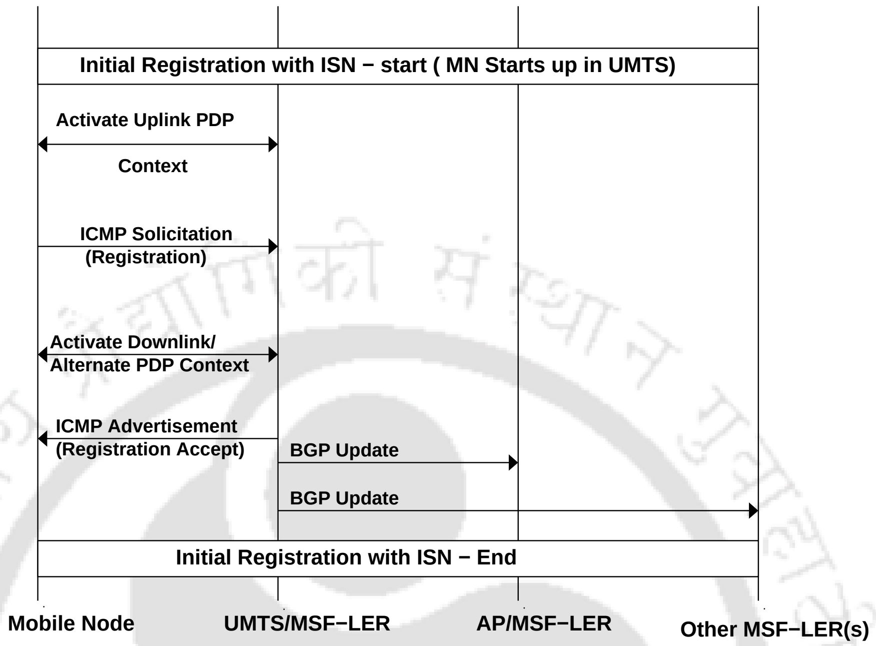

Figure 3.4: Initialization in UMTS Network

- Handover from IEEE 802.11 to UMTS – The Mobile Node is connected in the IEEE 802.11 network and roams out of the coverage area of IEEE 802.11 network.
- Handover within the IEEE 802.11 network – The Mobile Node is connected in the IEEE 802.11 network and moves from the coverage area of one AP to another AP.

Handoff from UMTS to IEEE 802.11

Figure 3.5 gives the procedure for handover from UMTS network to IEEE 802.11 network. Here UMTS Node-B is the present attachment point (PAP), and the IEEE 802.11 AP1 is the new attachment point (NAP). The steps involved in the handover procedure are as follows -

1. MN roams in to coverage area of IEEE 802.11 Access Point (AP1/MSF-LER) and starts association process with AP1/MSF-LER using its IEEE 802.11 interface.
2. After associating with AP1/MSF-LER, MN starts the registration process with ISN through AP1/MSF-LER.
3. While registering with AP1/MSF-LER it uses the Mobility Label initially assigned by GGSN-3G/MSF-LER.

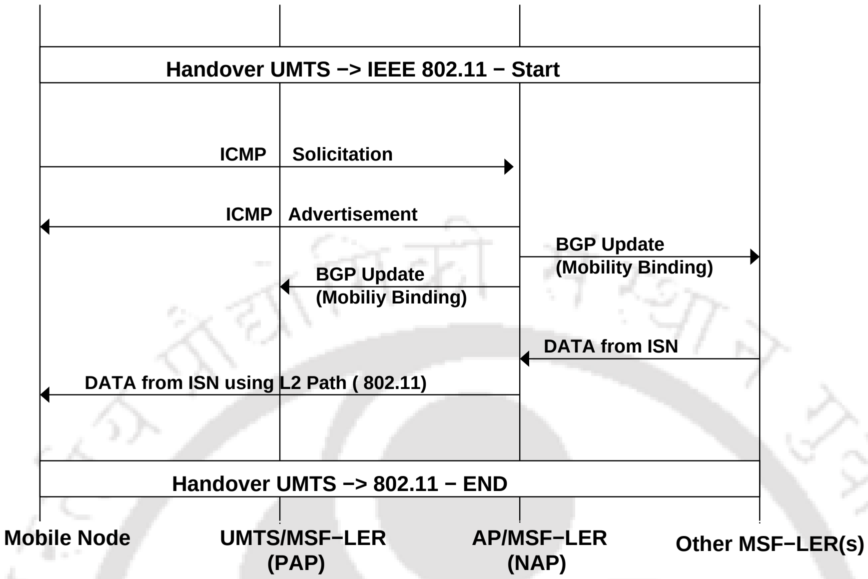

Figure 3.5: Handover Procedure - UMTS to IEEE 802.11

4. Once the registration along with the Mobility Binding update is completed, the MN receives the data traffic from AP1/MSF-LER via the L2 path formed by IEEE 802.11 MAC layer.

5. The MN drops the ‘Desired’ PDP context used for communication in UMTS network. The UMTS interface for the MN goes to the sleep mode, and wakes up periodically and sends dummy data through ‘Alternate’ PDP context to keep it alive.

6. This completes the handoff procedure from UMTS to IEEE 802.11.

Handoff from IEEE 802.11 to UMTS

Figure 3.6 gives the procedure for handover from IEEE 802.11 network to UMTS network. Here IEEE 802.11 AP1 is the present attachment point (PAP), and the UMTS Node-B is the new attachment point (NAP). The steps involved in the handover procedure are as follows -

1. The MN roams out of the coverage area of AP1/MSF-LER.

2. When the MN finds that there are no APs in range, with which it can associate, it starts the registration process via the GGSN-3G/MSF-LER. The ‘Alternate’ PDP Context required for starting the registration process is already in place.

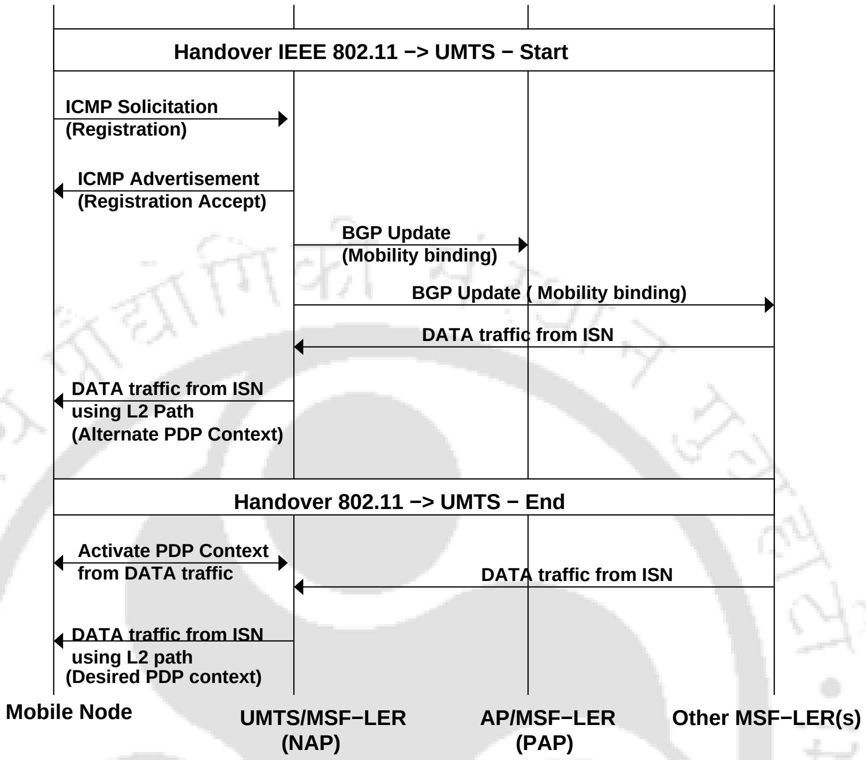

Figure 3.6: Handover Procedure - IEEE 802.11 to UMTS

3. Once the MN completes the registration process with the ISN via the GGSN-3G/MSF-LER, the ISN redirects the data traffic from AP1/MSF-LER to the GGSN-3G/MSF-LER.

4. At the GGSN-3G/MSF-LER the MSF functionality searches for the 'Alternate' PDP Context created in the earlier steps, and uses it to start forwarding the Data Traffic (IP Datagrams) to the MN temporarily. This is considered as the end of the Handover, as the MN starts receiving the IP Datagrams after registering with the GGSN-3G/MSF-LER.

5. The MSF functionality also starts the process for establishing the 'Desired' PDP Context required by the data traffic.

6. The IEEE 802.11 interface of the MN goes to sleep mode. However, it wakes up periodically to check for the presence of IEEE 802.11 network.

7. Once the 'Desired' PDP Context is established, the MSF functionality starts forwarding the IP Datagrams to the MN using 'Desired' PDP Context.

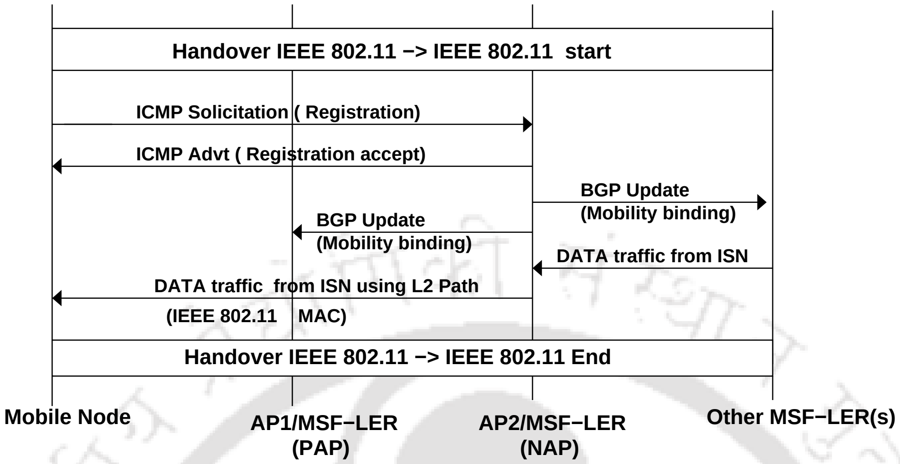

Figure 3.7: Handover Procedure - IEEE 802.11 to IEEE 802.11

Handoff from IEEE 802.11 to IEEE 802.11

Figure 3.7 gives the procedure for handover from one IEEE 802.11 network to another IEEE 802.11 network. Here IEEE 802.11 AP1 is the present attachment point (PAP), and the IEEE 802.11 AP2 is the new attachment point (NAP). The steps involved in the handover procedure are as follows -

1. When the MN moves out of the coverage area of AP1/MSF-LER and into the coverage area of AP2/MSF-LER, it performs a horizontal handoff from AP1/MSF-LER to AP2/MSF-LER and completes the association process with AP2/MSF-LER.
2. The MN then registers with the ISN through AP2/MSF-LER.
3. Once the MN registers with ISN through AP2/MSF-LER, the ISN forwards the data traffic (IP Datagrams) to the MN through AP2/MSF-LER using the L2 path provided by IEEE 802.11 MAC.
4. This completes the handover from the one Access Point to another inside the IEEE 802.11 network.

3.2 Simulations

The proposed scheme is implemented using Qualnet 5.0.1 Network Simulator. This scheme uses same IP address even when the MN moves from an old network to a new network. This can be made possible by using a central DHCP server which is placed in the ISN with

DHCP relays present in UMTS and WiFi networks (Figure 3.2). Qualnet however does not allow assigning same IP address to both the interfaces of the MN. To accommodate this the following changes were made -

1. MSF-Database – The MSF-DB was changed to associate a 'set of IP Addresses' with each record. This set would consist of the IP addresses being assigned to each of the interfaces of the Mobile Node.

2. Datagram Delivery – At MSF-LER1 the destination IP address of the IP Datagram is compared with each of IP addresses in the IP Address set associated with the records.

3. Maintaining the Data Session –

   (a) When the IP Datagram is received at the Mobile Node, the destination IP Address of the incoming IP Datagram is used as the source IP Address of the outgoing IP Datagram.

   (b) The Mobile Node transmits the IP Datagram over the interface which it has used for registering with the current MSF-LER.

   (c) The Data Session end point at the Corresponding Node (CN) finds the same IP address for incoming IP Datagrams even when the MN moves into another network and uses an interface having a different IP address.

3.2.1 Scenario Setup

The scenario setup is similar as shown in figure 3.2. The simulation has been done in an ideal scenario, assuming that the user always have a channel to transmit. So, only one mobile node is considered for initial simulations to show the effect of handover. However, the effect of channel contention is also analyzed and compared with Mobile-IP based handover solutions. The handover time, end-to-end delay at the time of handover and packet loss are calculated in an ideal scenario, and compared with the MIP based pre-registration and post-registration schemes. For this scenario the effects of vertical and horizontal handover has been studied with UDP traffic of data rate 1 Mbps. The application traffic used for this purpose is the Constant Bit Rate (CBR) traffic, which uses UDP for transporting the data packets to the destination. The behavior of the UDP traffic is analyzed based on the following factors -

1. Handover Duration.

2. End-to-End Delay experienced by UDP Packets.

3. Packet Loss.

The handover duration and end-to-end delay are calculated as follows;

- **UDP Handover Duration:** Time of first UDP packet arrival at MN after handover - Time of last UDP packet arrival at MN before handover

- **Layer 2 Handover Duration:** Time between the first probe request message sent by the MN and the arrival of a re-association response message.

- **Layer 3 Handover Duration:** Time between ICMP solicitation message sent by the MN and the BGP updates received at all MSF-LERs. This is basically the time required for mobility binding updates.

- **End-to-End Delay:** Time of arrival of CBR packet at MN - Time of CBR packet transmission at CN

The total handover duration for UMTS to IEEE 802.11 handover is the total time required for Layer 2 handover and Layer 3 handover. However, for IEEE 802.11 to UMTS handover the total handover duration is the time required for Layer 2 and Layer 3 handover plus the time required for scanning alternate APs.

The scenario depicted in figure 3.2 is executed twice –

1. In the first execution, the Mobile Node initiates in the UMTS network, then moves into the coverage area of AP1/MSF-LER of WLAN network and finally stops in the coverage area of AP2/MSF-LER (Refer to path of MN1 in figure 3.2).

2. In the second execution, the Mobile Node initiates in the coverage area of AP2/MSF-LER, then moves into the coverage area of AP1/MSF-LER and finally hands over to the UMTS network (Refer to path of MN2 in figure 3.2).

The scenario parameters are given in Table 3.1.

3.2.2 Analysis for UDP Traffic

Handover from UMTS to IEEE 802.11

Figure 3.8 shows the graph for handover from UMTS to IEEE 802.11 network. During the handover, as the MN is always in the UMTS coverage area, it keeps on receiving

Table 3.1: Scenario Parameters

Serial No.	**Parameter**	**Value**
1	Kind of Traffic	CBR (UDP)
2	Data Rate	1Mbps
3	CBR Packet Size	250 bytes
5	Number of CBR Packets	990000
6	CBR Packet Interval	2ms
7	Scenario Duration	1700s
8	Mobile Node Speed	1.2m/s
9	PDP Context Max Idle Time	45s
10	Registration Lifetime	20s
11	Max Registration retries	3
12	Registration retry interval	3s
13	UMTS Maximum Bandwidth	2 Mbps
14	IEEE 802.11 Maximum Bandwidth	11 Mbps

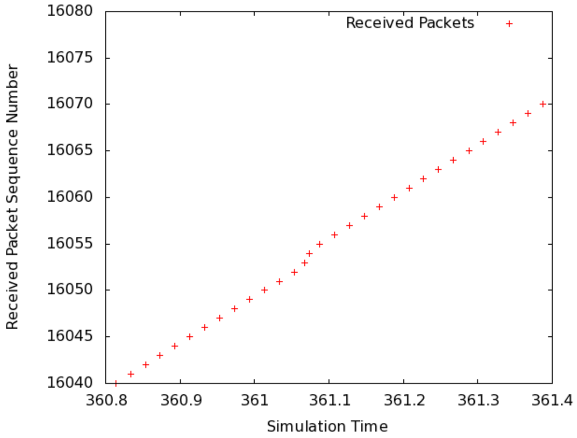

Figure 3.8: Handover UMTS to IEEE 802.11 (1 Mbps CBR)

packets from its UMTS interface. Once the MN finishes the Mobility Binding update, it starts receiving packets on its IEEE 802.11 interface. As the graphs shows, there is no break in the arrival of the packets. The handover procedure starts at 361.0916 seconds. The Mobility Binding update finishes at 361.0921 seconds, at which point a slight surge in the rate can be seen, at which the packets are being received. This occurs as the MN receives packets on both its interfaces. This could result in packets coming out of sequence, which could lead to some packet loss, if the application receiving the packets rejects out of sequence packets. During handover from UMTS to IEEE 802.11 network, data packets experience more delay in the UMTS network. As a result, when the Mobility Binding Update completes, some data packets remain in the old path through the GGSN-3G/MSF-LER. These packets are received through the UMTS interface even when the handover to IEEE 802.11 is complete. The active time can be determined by sending a probe packet to the CN, so as to get the round trip delay. The UMTS network goes to sleep mode and wakes up periodically to send dummy packets using ‘Alternate’ PDP context to keep it alive.

Handover from IEEE 802.11 to UMTS

Figure 3.9 shows the graph for handover from IEEE 802.11 to UMTS. The MN detects that it can no longer associate with any of the AP/MSF-LERs and starts the process of registering with the ISN via the GGSN-3G/MSF-LER. MN does not receive any packets till the time it has completed Registration and Mobility Binding update with the ISN. The MN receives the last packet before handover at 967.2102 seconds. At this point MN

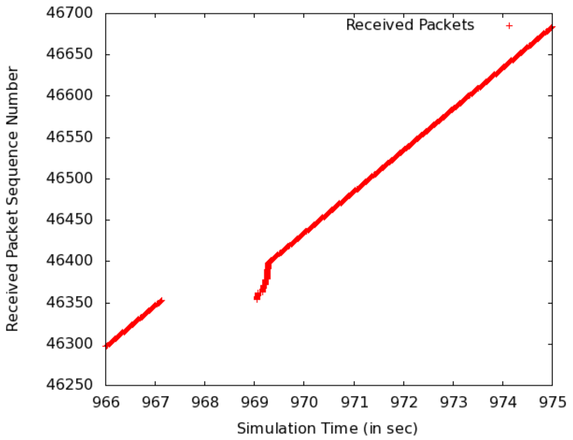

Figure 3.9: Handover IEEE 802.11 to UMTS (1 Mbps CBR)

starts scanning for a new AP/MSF-LER, finds that there are no AP/MSF-LERs in range, and so starts the registration process with ISN at 968.9423 seconds. The Registration and Mobility Binding process finishes at 969.0121 seconds. The GGSN-3G/MSF-LER starts using the 'Alternate' PDP Context instead. The MN receives the first packet after the handover at 969.0182 seconds, using the 'Alternate' PDP Context. The UMTS/MSF-ER uses the 'Alternate' PDP Context till time 969.0541 seconds. During this time the packets are received at lower data rates. At 969.0548 seconds, the 'Desired' PDP Context setup finishes, and the GGSN-3G/MSF-LER switches the traffic over to the 'Desired' PDP Context (with desired data rates). Initially the queued packets at the UMTS are send at data burst, and then packets are received at normal data rates. After switching over to the 'Desired' PDP Context, some packets are received out of sequence, as the packets which used the 'Alternate' PDP Context experience more delay than those being received through the 'Desired' PDP Context. After the handover is complete, the IEEE 802.11 interface goes to sleep mode and wakes up periodically to scan for the presence of IEEE 802.11 network.

Handover from IEEE 802.11 to IEEE 802.11

Figure 3.10 depicts the handover from IEEE 802.11 to IEEE 802.11. The MN detects that it needs to perform a horizontal handoff from its current AP/MSF-LER to another AP/MSF-LER. It starts the scanning process, associates with the new AP/MSF-LER and then starts the registration and Mobility Binding update procedure for the new AP/MSF-LER. From the start of the scanning till the end of Mobility Update, the MN does not

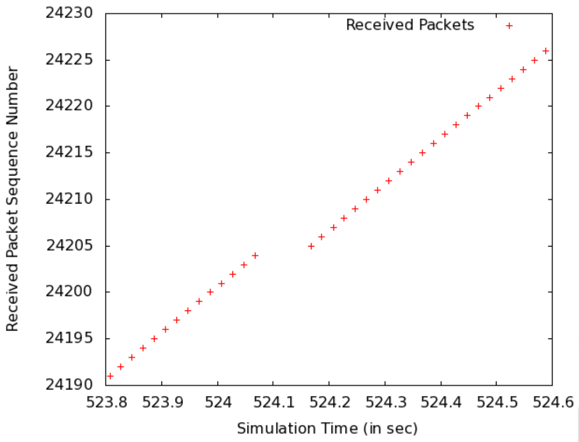

Figure 3.10: Handover IEEE 802.11 to IEEE 802.11 (1 Mbps CBR)

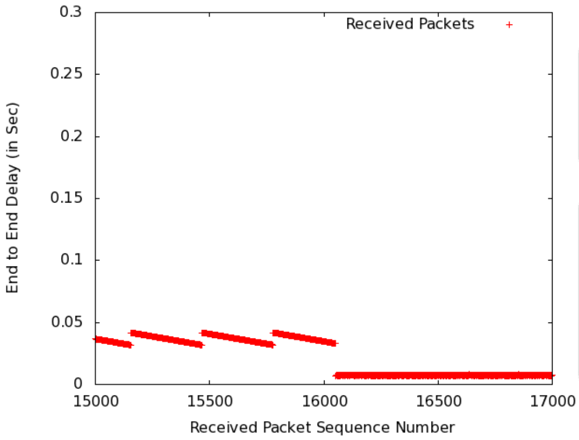

Figure 3.11: Handover UMTS to IEEE 802.11 (1 Mbps CBR)

receive any packets, which are dropped. This is shown by a gap in graph.

End-To-End Delay

Figure 3.11 shows the end-to-end delay for handover from UMTS to IEEE 802.11 network. As shown in the graph the handover from UMTS to IEEE 802.11 starts after the CBR Packet number 16053. Before the handover the MN is in the UMTS network and the packets experience higher End-To-End Delay. The End-To-End delay drops as it moves in to the IEEE 802.11 network.

As shown in the graph (Figure 3.12) when the MN moves from the IEEE 802.11 network to the UMTS network the End-To-End Delay increases. During this time it can

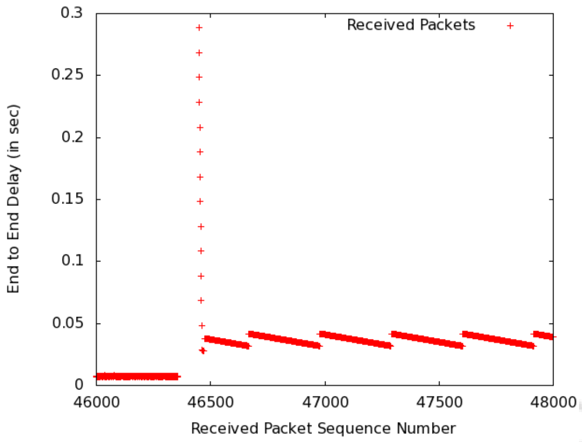

Figure 3.12: Handover IEEE 802.11 to UMTS (1 Mbps CBR)

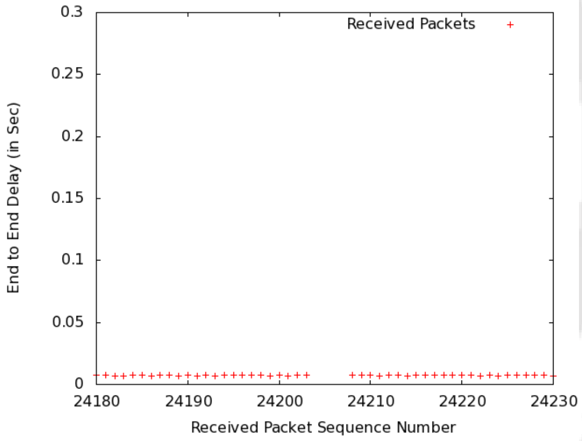

Figure 3.13: Handover IEEE 802.11 to IEEE 802.11 (1 Mbps CBR)

be seen that some packets experience more delay. This is due to the use of the ‘Alternate’ PDP Context during the handover.

As shown in the graph (Figure 3.13) there is no significant change in the End-To-End Delay of the packets after the handover.

3.3 Comparison with Existing Systems

The performance of vertical handover in proposed framework is compared with other existing works - mainly MIP based handover, pre-registration handoff [29] and post-registration handoff [22]. In Table 3.2, the Layer 3 Handover delay (in ms) for the proposed

Table 3.2: Layer 3 Handover Delay (in ms) Comparison (1Mbps CBR)

	Mobile IP	**Pre Registration HO [29]**	**Post Registration HO [22]**	**Proposed Scheme**
UMTS to WLAN	12	16	14	8
WLAN to UMTS	18	16	14	12.1
WLAN to WLAN	12	12	10	9.4

Table 3.3: Number of Packet Drops Comparison (1Mbps CBR)

	Mobile IP	**Pre Registration HO [29]**	**Post Registration HO [22]**	**Proposed Scheme**
UMTS to WLAN	6	4	3	0
WLAN to UMTS	8	7	6	7
WLAN to WLAN	4	4	5	3

scheme is compared with various existing schemes that uses Mobile IP for vertical handover between UMTS and WLAN networks. It can be noted that Layer 2 handover delay is similar and depends only on physical data rate for both Mobile IP based scheme and our proposed scheme. For the Mobile IP based handover simulation, similar scenario is used as given in [32], with 1 Mbps data rate, 2 Mbps bandwidth for UMTS network and 11 Mbps for IEEE 802.11 network. The WLAN networks and the UMTS networks are being connected to common Internet gateways. As seen from the table, the handover delay is minimum in ISN framework compared to other exising works. Table 3.3 shows number of packet loss during handover procedure. Again the proposed scheme reduces the number of average packet loss in the three case of UMTS to WLAN, WLAN to WLAN and UMTS to UMTS handovers. For WLAN to UMTS handover, the number of average packet loss is at per the existing schemes.

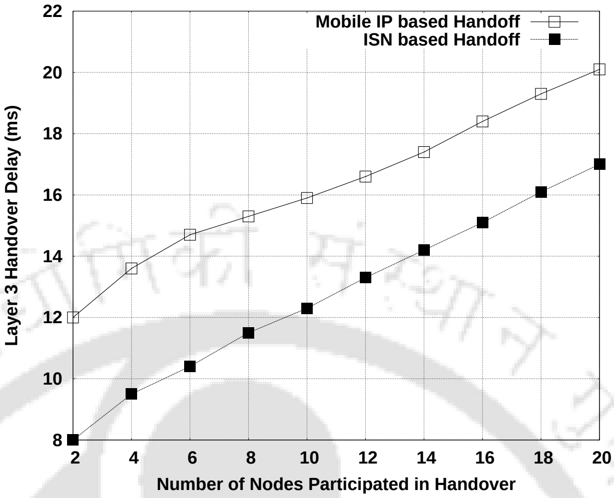

Figure 3.14: Handover UMTS to IEEE 802.11 (1 Mbps CBR)

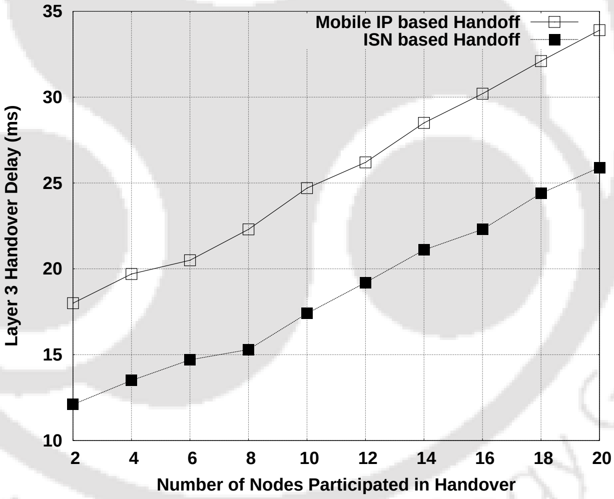

Figure 3.15: Handover IEEE 802.11 to UMTS (1 Mbps CBR)

Figure 3.14, Figure 3.15 and Figure 3.16 show a comparison between Mobile IP based handover and the proposed ISN based handover for varying number of nodes participated in handover. The figures shows the effect of channel contention in handover delay. From the simulation traces, it has been observed, that mobility binding update time at ISN does not affected as number of MN is increased. This is because the ISN is a wired backbone and connected like a mesh structure. The mobility binding update is broadcast at the ISN. The handover delay is increased because of channel contention at the wireless media. However, the handover delay is far less compared to Mobile-IP based handover scheme.

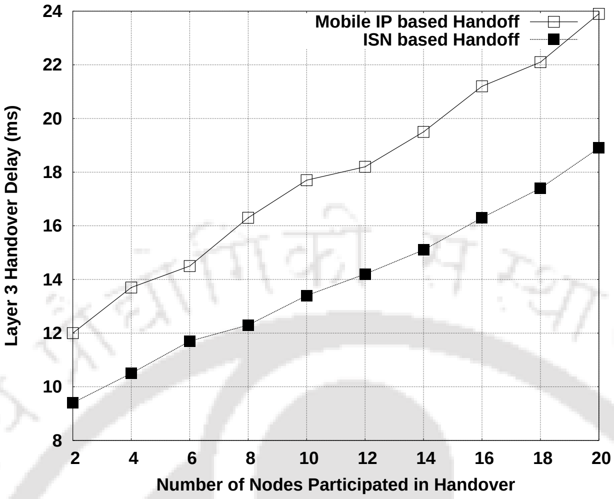

Figure 3.16: Handover IEEE 802.11 to IEEE 802.11 (1 Mbps CBR)

Table 3.4: Handover Duration Summary

Handover Metric	**UMTS to 802.11 (Seconds)**		**802.11 to UMTS (Seconds)**		**802.11 to 802.11 (Seconds)**	
	1Mbps	2Mbps	1Mbps	2Mbps	1Mbps	2Mbps
Layer 2 Handover Duration	0.0010	0.0007	0.0054	0.0054	0.0010	0.0007
Layer 3 Handover Duration (Mobility Binding Updates)	0.0082	0.0080	0.0121	0.0116	0.0094	0.0093
Packet Loss	0	0	7	8	3	2

3.4 Discussion

In this section the pros and cons of handover optimization in the ISN based framework is discussed with a brief discussion about handover authentication.

3.4.1 Handover Optimization

In this chapter, a Loosely Coupled architecture is being focused as it requires minimal changes to the existing systems and does not rely on Mobile IP. So there is no concept of a home network and therefore there is no need to register with the HA. In addition there is no need of CoA(care of address). The main advantage of this scheme is that it eliminates

Table 3.5: Average End-To-End Delay for 1Mbps CBR (in Seconds)

	UMTS to 802.11	**802.11 to UMTS**	**IEEE 802.11 to 802.11**	**UMTS Stationary**	**802.11 Stationary**
Before Handover	0.0218	0.0054	0.0054	0.0236	0.0054
After Handover	0.0054	0.0324	0.0054	0.0238	0.0054

sub-optimal routing(triangular routing and bidirectional tunneling) that is inherent in the mobility management schemes based on MobileIPv4/v6. The proposed framework is based on a general mobility management framework proposed by Oleg Berzin [23], [24] which is a generalized solution for any access network. This framework is independent of Mobile IP and is expected to eliminate user facing delay and packet loss probabilities due to triangular routing resulting in better performance. The presence/absence of the IEEE 802.11 network is defined as the criteria for initiating a handoff using RSSI as the handoff criterion.

A number of simulations were carried out to study the effect of the proposed method on the behavior of CBR (UDP) traffic with respect to Handover Duration, mobility binding duration and End-To-End delay. The results are summarized in Table 3.4 and Table 3.5. Table 3.4 shows the parameters for both 1Mbps and 2Mbps data rate. When the handover occurs, the packets which are in transit get lost. Once the mobility binding is over the packets are forwarded through new path. The simulation results have shown that during handoff from UMTS to IEEE 802.11 network, the Handover Duration is equal to the time required for completing the Mobility Binding update ($\approx$ 8ms). There is also no packet loss during the handoff as it continues to receives data packets on its UMTS interface while the Mobile Node scans for a suitable AP/MSF-LER.

During the handover from IEEE 802.11 to UMTS, a lot of time is spent on scanning for a suitable AP/MSF-LER. The total duration including scanning of alternate APs is $\approx$ 832ms(1Mbps), out of which the Mobility Binding Update takes $\approx$ 12.1ms, which is the actual handover duration. In this case, around 800ms is used for scanning alternate APs. In [81], a proactive AP scanning approach for horizontal handover in WLAN networks is proposed which saves a substantial amount of scanning time. This interleaved scanning method eliminates the need for scanning during handoff and makes fast handoff possible.

Incorporating this scanning techniques in the proposed architecture can guarantee a better performance. The high handoff latency experienced due to the need for creating a PDP Context is reduced by the use of an alternate PDP Context. The pro-active creation of an alternate PDP Context reduces PDP Context set up time for registration messages during handover thereby reducing handoff latencies. The PDP Context set up time for data traffic is reduced, by using the ‘Alternate’ PDP Context to transfer packets to the MN till the ‘Desired’ PDP Context is created.

From the simulation results, it can be noticed that the End-To-End delay undergoes a sudden change when the handoff occurs between UMTS and IEEE 802.11 networks. This is because the packets have to traverse more number of nodes in the UMTS network than the WLAN network and hence experience greater delays in the UMTS network. This change in End-To-End delay can lead to jitter during the handoff and can affect audio/video applications.

3.4.2 Authentication, Authorization and Accounting

Figure 3.2 shows an Authentication, Authorization and Accounting (AAA) Server placed in the ISN. The AAA Server is responsible for authenticating and authorizing MNs who request the mobility services provided by the ISN. The AAA can also take care of billing the MN on the basis of the amount of usage based on criteria like - duration for which the mobility services were availed or amount of data downloaded while using the mobility services. In the proposed scheme, during the initial registration with the ISN, the MN is assigned a Mobility Label. This Mobility Label is used by the MN for subsequent registration with the ISN. As the MN stores the Mobility Label with itself, this leads to various security risks (e.g Replay Attacks). The proposed scheme assumes that the MN is a trusted device, however the security risks which arise due to storing the Mobility Label with the MN need to be addressed.

A challenge-handshake based authentication can be used to authenticate the mobile node. When the mobile node switches from one network to another network, the PAP sends a challenge to the MN. At the same time PAP sends all credentials with challenge to NAP for future authentication. After the handover, MN sends the hash of the challenge together with its credentials such as password to the NAP. NAP can then validate the mobile node by comparing the hash value. If agreed, authentication is accepted.

3.5 Summary

In this chapter a new framework for mobility management between UMTS and IEEE 802.11 networks has been proposed using the Intermediate Switching Network(ISN) which is based on MPLS and MP-BGP for optimal packet delivery. The ISN is integrated with the UMTS network at the GGSN-3G and with the IEEE 802.11 network at the AP. The use of the switching network avoids sub-optimal routing (triangular routing + bidirectional tunneling) and also allows the user to experience higher data rates when in the IEEE 802.11 network. Switching of data traffic based on MPLS and MP-BGP reduces the handoff delay. The changes required due to the integration of ISN has to be made only at the GGSN-3G in the UMTS network and at the AP in the IEEE 802.11 networks. Simulation results shows that this ISN based integration framework works well with UDP data traffic and supports the norms of multimedia data service requirements. Thus this MPLS and MP-BGP based architecture provides with an efficient technique for handoff between heterogeneous networks and allows the user with the opportunity to experience better data rates as compared with Mobile IP based systems.

Though this chapter gives a detailed performance measure of the proposed ISN based vertical handover framework, the data traffic considered is UDP only. As most of the traffics in the Internet uses Transmission Control Protocol (TCP) at the transport layer, we must also look at TCP data traffic. The next chapter evaluates the performance of the ISN based framework for TCP traffics, and proposes an improvement with amendment over the standard TCP protocol, to work well with this scheme.

Chapter 4

Evaluation of the End-to-End TCP Performance for Vertical Handover using Intermediate Switching Network

Transmission Control Protocol (TCP) is the most widely used end-to-end transmission layer protocol for today's data network to provide reliable and service-oriented data delivery. TCP is designed mainly to perform on wired networks. So packet loss is considered as the cause of congestion in the network, and upon detection of packet loss, TCP reduces the sending rate by reducing the Congestion Window(CWnd) to a lower value to cope up with network congestion. In wireless networks, the communication medium is error prone, and packet loss can occur because of several reasons like the channel fading, shadowing, hand-off and other radio effects. TCP faces several problems in the wireless networks [82], which can be summarized as follows,

1. Packet losses due to the radio effects are misinterpreted as congestion, and TCP unnecessarily drops its congestion window(CWnd) value to a lower one. The problem becomes severe for the high bit error rate (BER) and error prone channels, where size of the CWnd tends to stay small for a long period of time.

2. TCP computes retransmission timeout(RTO) on the basis of the retransmission timer(RTT) values. So an unexpected increase of RTT could lead to spurious RTO expiration leading to lowering of CWnd.

3. TCP uses an exponential back-off mechanism for packet retransmission. With small CWnd size, the exponential back-off increases the retransmission timeout (RTO), resulting in long periods of silence or connection break-down.

4. TCP uses a set of retransmission timers at the transport layer, which are independent from the link layer timers. Uses of independent timers at the link layer and the transport layer may trigger unnecessary retransmissions.

The problems of the TCP become more severe during the vertical handover between two different wireless technologies. Vertical handover introduces additional problems over TCP as follows,

1. Different wireless technologies operate in different data rates. For example, IEEE 802.11 WLAN can operate up to 600 Mbps for IEEE 802.11n, whereas the UMTS operates theoretically up to 42 Mbps when high speed packet access (HSPA) is implemented in the network. However, in practice, users of an UMTS network can expect the transfer rate to go up to 7.2 Mbps with HSDPA handsets. Thus there is a significant gap between the data rate for an UMTS network and a WLAN network. After handover, TCP resumes its old values of CWnd and RTO, which are not suitable for the new network. So the performance degrades severely when handover occurs from a slow network to a fast network because of the low CWnd and high RTO of the old network. Similarly several packets are dropped and TCP connection breaks down due to the spurious timeouts when handover takes place from a fast network to a slow network. Spurious timeout is defined as a timeout which would not have happened if the sender waited long enough. It is a timeout resulting in retransmission due to a segment being delayed, but not lost, after RTO expires [83].

2. With a high-latency link technologies, such as the UMTS and its high buffering, it takes several seconds for the TCP CWnd to reach the new path capacity [84].

This chapter evaluates the TCP performance for vertical handover between an UMTS and a WLAN networks, using the ISN framework. Among the different TCP protocol variants, the conventional approach for TCP improvements over the wireless networks, called the *'Wireless Profiled TCP'* (WP-TCP) [42, 82] is used in this chapter as the base protocol. A naive improvement over the conventional TCP, called ISN-TCP, has been proposed in this chapter to mitigate the problem for conventional TCP during vertical handover. The performance analysis for ISN-TCP shows that though ISN-TCP performs better than the conventional TCP, it fails to mitigate all the problems associated during the vertical handover between UMTS and WiFi networks over the ISN based framework. This chapter further extends the analysis for the UMTS-WLAN handover using ISN framework, and proposes an improved TCP variant over the ISN-TCP, namely ISN-TCP-PLUS. In ISN-TCP-PLUS, TCP connection maintenance during handover is handled using a cross-layer interaction between the transport and the network layer, and estimation of updated TCP parameters after handover. By filtering out the duplicate ACKs(DACKs) and calculating the RTT of the new network on-the-fly, ISN-TCP-PLUS improves the performance of the TCP significantly during handover. The proposed scheme uses an approximation in CWnd calculation, similar to the approaches used for the equation based TCP congestion control [85,86]. The performance of the ISN-TCP-PLUS has been analyzed using simulation results.

The rest of the chapter is organized as follows. The performance of the WP-TCP over ISN based framework during handover has been reported and analyzed in section 4.1. In section 4.2, the design of ISN-TCP is discussed with detail analysis of performance evaluation through simulation results for the WLAN to the UMTS handover and vice-versa, using the ISN based framework. The further improvement of the TCP variant for the UMTS to the WLAN vertical handover, called the ISN-TCP-PLUS, is discussed in section 4.3. Section 4.4 reports the performance of the ISN-TCP-PLUS using simulation results. Finally, section 4.5 concludes the chapter.

4.1 Performance Evaluation of TCP for ISN Based Framework

The TCP performance is evaluated over the ISN based framework using Qualnet 5.0.1 [87] network simulator. The simulation scenario is based on the ISN architecture shown in Figure 3.2, in Chapter 3. Two scenarios have been used for the simulation,

1. In first case, initially the MN is in the UMTS network, and moves into coverage area of AP1 in the WLAN network as shown in Figure 3.2. It finally moves inside the coverage area of AP2 in the WLAN network.

2. In second case, initially the mobile node is in the WLAN network, and moves out of the WLAN network. It finally stops in the UMTS network.

The TCP version used for simulation is TCP new-Reno with wireless profiled modifications (WP-TCP) as proposed in [42]. WP-TCP is implemented with all mandatory

Table 4.1: Simulation Parameters

Parameter	Value
Application Traffic	FTP/GENERIC
Packet Size	512 Bytes
Number of Packets	40000
Mobile Node Speed	1.2m/s
PDP Context Max Idle Time	45s
Registration Lifetime	20s
Max Number of Registration Retries	3
Registration Retry Interval	3s

requirements (RFC 1112 [88], RFC 2581 [89] and the selective acknowledgement [90]), and some important optional requirements such as large initial window (RFC 3390 [91]) and time-stamp option (RFC 1323 [92]) for RTT measurement. The maximum CWnd size is taken as 31 packets, and DACK threshold is taken as 5 packets. The MN acts as the TCP receiver and the CN acts as the TCP sender. The simulation parameters are shown in Table 4.1.

To evaluate the performance of TCP during handover, the CWnd and duplicate packets sent during handover have been measured.

4.1.1 UMTS to the WLAN Handover

The handover from the UMTS to the WLAN network starts at 474.8 seconds. The simulation graphs are shown in Figure 4.1 and Figure 4.2. During the handover significant amount of packets are dropped from the UMTS interface. It can be seen from Figure 4.1 that, after the handover procedure gets completed, duplicate packets are transmitted, and the packets are delivered out of order. As a result, CWnd drops to its initial value, as shown in Figure 4.2. It has been observed from the simulation traces that 24 Kbytes of data have been retransmitted due to the handover. From extensive simulation results it has been also observed that amount of data retransmitted increases with the increase of packet size and the number of simultaneous TCP connections. It can also be observed from Figure 4.2, that CWnd drops twice - once during handover, and next after the handover gets complete. After the handover, the CWnd is dropped because of the large amount of duplicate packet transmissions.

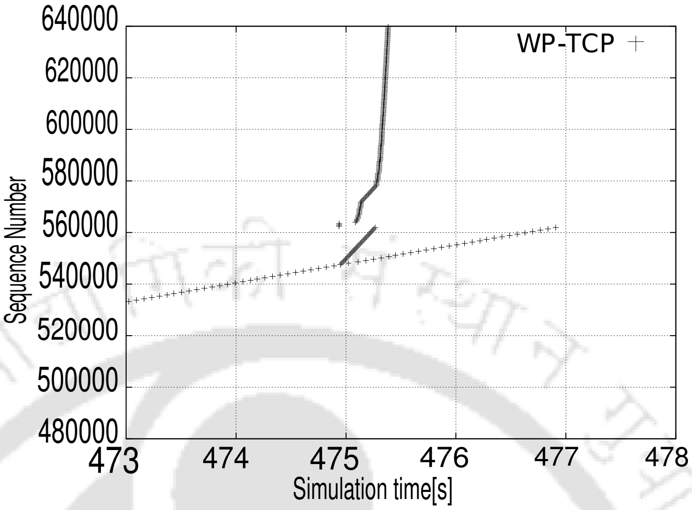

Figure 4.1: Data Sent (UMTS → WLAN)

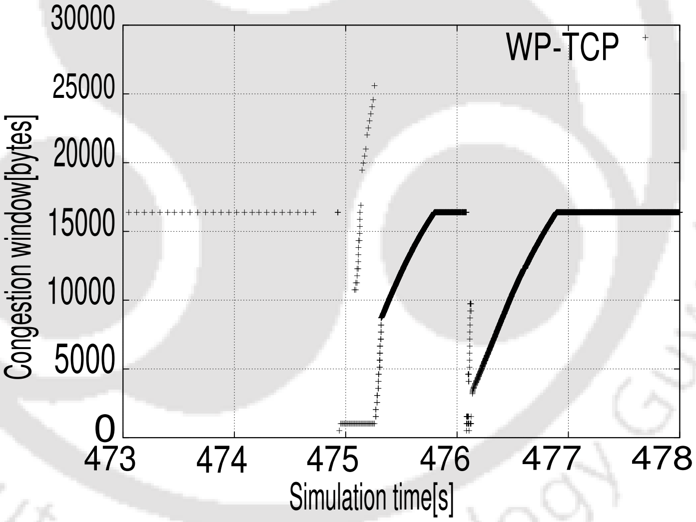

Figure 4.2: CWnd (UMTS → WLAN)

4.1.2 WLAN to the UMTS Handover

The handover procedure from the WLAN network to the UMTS network is initiated at 1150 sec. During the handover, multiple RTO occur due to large difference in the RTT values in the UMTS network and the WLAN network. In Figure 4.3, data receiving stops at 1150.67 secs, and data receiving again starts at 1156.14 sec. This break in the transmission is because of the multiple RTOs that occur at the sender side. At every retransmit timer firing event, TCP sender reduces the congestion window to one segment, retransmits that

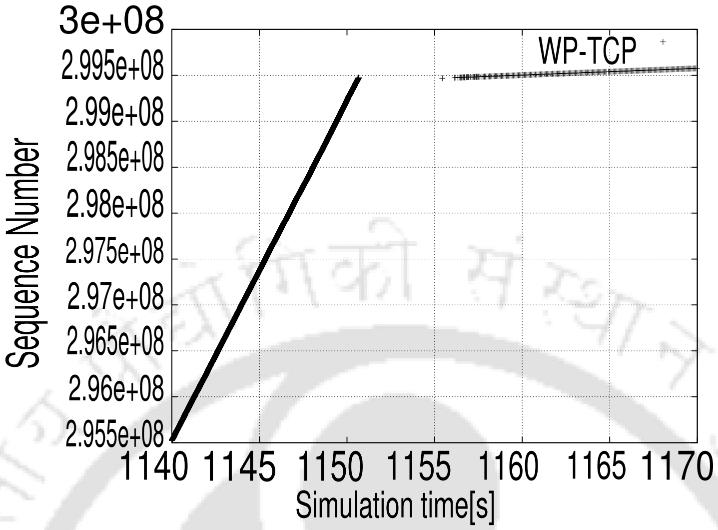

Figure 4.3: Data Sent (WLAN → UMTS)

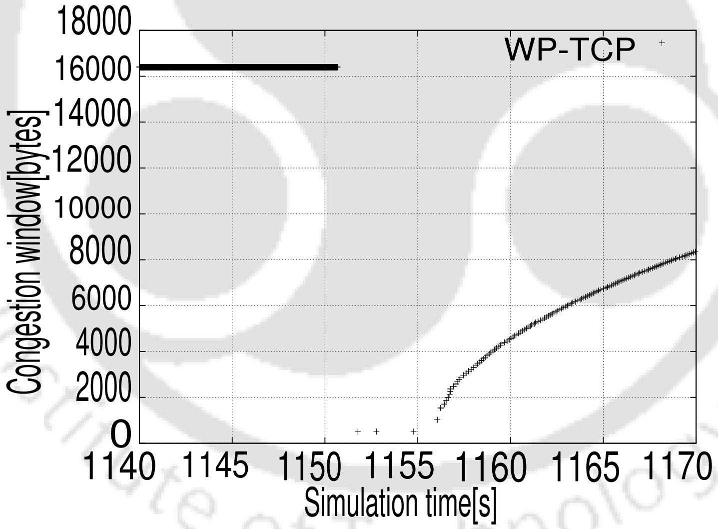

Figure 4.4: CWnd (WLAN → UMTS)

segment, and doubles up the retransmit timer. The drop in congestion window is shown in Figure 4.4. In the present simulation scenario, three consecutive RTOs occur before the first packet is successfully delivered after the handover. It has been observed from the simulation traces that even after doubling up the retransmit timer, the updated RTO value is not sufficient for the UMTS network. Hence a mechanism is required for the TCP RTT estimation after the handover, that overcomes this drawback.

The observations from simulation analysis of WP-TCP over ISN based vertical handover framework is summarized below.

1. During the UMTS to the WLAN handover, CWnd drops to its initial value because of two reasons,
    (a) The RTO at the UMTS network is less than handover delay. Thus during handover, the retransmission timer expires, and TCP resets CWnd value to its initial value.
    (b) Significant number of packets are dropped from the UMTS interfaces during handover. These TCP packets are retransmitted through the WLAN interface after the handover gets completed. This is because, the TCP sender (here the CN) is not aware of the impending handover. The packet loss during the handover generates DACKs. Thus the DACK threshold (which is normally 5 packets for WP-TCP) gets expired, and TCP resets its CWnd.
2. Premature RTOs occur during the handover from the WLAN to the UMTS. This is because RTOs are calculated based on the RTT values. The RTT for the WLAN network is much lower compared to the UMTS network. Because of these premature RTOs, CWnd drops to one segment, and TCP goes to the slow-start phase.

4.2 ISN-TCP: A Naive Improvement over Conventional TCP

To solve the problem of duplicate packet delivery and premature RTOs, a naive variant of conventional TCP, called ISN-TCP is first proposed in this chapter for vertical handover using ISN based framework. In ISN-TCP, a sub-layer has been introduced between the transport and the network layer, at the two end nodes of a communication path, with minimal dependencies on the intermediate nodes. No additional functionality is required in the network architecture. Upon notification of handover, the intermediate layer executes two processes at the MN, called PR_{MN} as receiver process and PS_{MN} as sending process. Two similar processes are executed at CN, called PR_{CN} and PS_{CN}. PR_{MN}, PS_{MN}, PR_{CN} and PS_{CN} interact with the corresponding TCP process at the MN (TCP_{MN}) and the CN (TCP_{CN}).

4.2.1 The Handover from the UMTS to the WLAN

The detailed handover procedure from an UMTS network to a WLAN network is as follows.

1. When the MN becomes aware of an impending handover with the receipt of a Layer 2 trigger, the PR_{MN} process saves the sequence number of the last packet ($SeqL\_MN$) on the old interface, and then sends a *handover notification packet* to the PR_{CN}.
2. The PR_{CN} process also saves the sequence number of the last packet ($SeqL\_CN$) on the old network, and handover begins.
3. The MN sends the path establishment notice after handover to the PR_{MN} process. The MN estimates the RTT, and sends a path establishment notification to the PR_{CN}. MN also updates the parameters at TCP_{MN}. This notification includes the estimated value of the bandwidth and the RTT by the MN.
4. TCP_{CN} estimates the RTT value, and updates parameters. Both the MN and the CN save the sequence number of the first packet ($SeqF\_MN$ and $SeqF\_CN$) on the new interface.
5. After this, the MN forwards packets with the sequence number $SeqL\_MN$ to $SeqF\_MN$ to the CN. Similarly the CN forwards packets with the sequence number $SeqL\_CN$ to $SeqF\_CN$ to the MN.

While handing over from an UMTS network to a WLAN network, the problem faced are mainly of the packet loss, packet reordering and the network under-utilization. Since the RTT of the WLAN is much smaller than that of the UMTS network, the packets arrive out-of-order at the receiver generating $DACKs$ to falsely trigger TCPs fast retransmission of the in-flight packets. ISN-TCP solves this problem by closing the old link immediately after the handover, and falsely create a situation of packet loss to avoid the problem of packet reordering. TCP_{CN} is also notified to avoid taking any congestion avoidance actions. The CN and the MN know exactly what packets are to be resent as the sequence number of the last packet arrived on the old interface before handover and the first packet on the new interface after handover are stored. After the new path is established, the leftover packets are sent from either side. So packets do not come out-of-order in ISN-TCP.

4.2.2 The Handover from the WLAN to the UMTS

The detailed procedure is as follows,

1. When the MN sends a Layer-2 trigger to the process PR_{MN} indicating a possible handover, it sends a handover notification packet including type of handover and Zero Window Advertisements (ZWA) to the PS_{CN}. A sender that receives a ZWA must stop sending further packets until it receives a positive window.
2. The PR_{MN} process at the MN freezes its TCP process.
3. The PS_{CN} process notifies about the impending handover to its TCP_{CN} process, and freezes it.
4. After the handover is complete, the MN sends the path establishment notification to the PR_{MN}, and estimates the RTT and the CWnd. These values are updated at PR_{MN}.
5. A notification of new path establishment by the MN is sent to the PR_{CN} process and the estimation of the RTT takes place by the CN, followed by the updation of the parameters.
6. This update notification is sent to the PS_{MN}, and PS_{CN} sends unfreeze notification to TCP_{CN} process, and TCP becomes active once again with new parameters.

Here, while handing over from the WLAN to the UMTS, the problem faced is of spurious timeouts. The drastic increase in RTT results in spurious timeouts, and as a result TCP enters the slow start phase by reducing the CWnd to 1 and injecting too many packets into the slow network. In ISN-TCP both the CN and the MN measure RTT and bandwidth after handover and the estimation of the RTT at the new interface takes place. For the TCP to adapt readily to the new link characteristics, ISN-TCP estimates the RTT and the available bandwidth.

4.2.3 Analysis of ISN-TCP for the UMTS-WLAN Handover

The performance of ISN-TCP for the UMTS-WLAN handover is evaluated using the similar simulation scenario as described earlier in section 4.1.

The Handover from the UMTS to the WLAN:

The simulation results for ISN-TCP is shown in Figure 4.5 and Figure 4.6. From the simulation analysis for the UMTS to the WLAN handover, it has been observed that ISN-TCP can reduce number of CWnd drops during handover. However, it can not

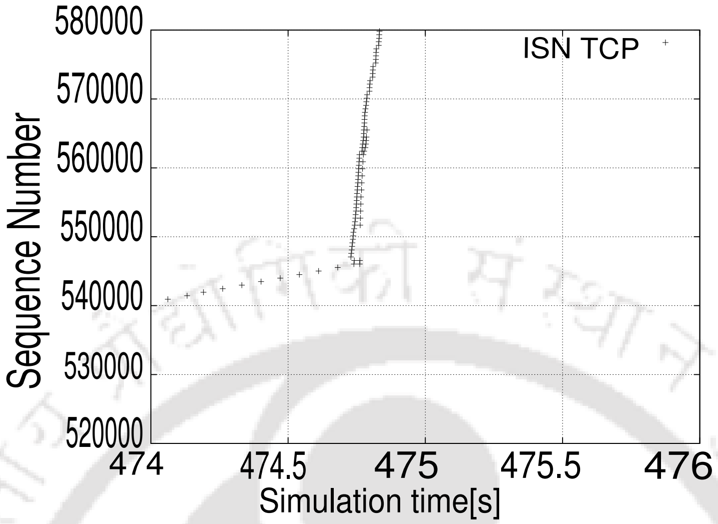

Figure 4.5: Data Sent (UMTS → WLAN)

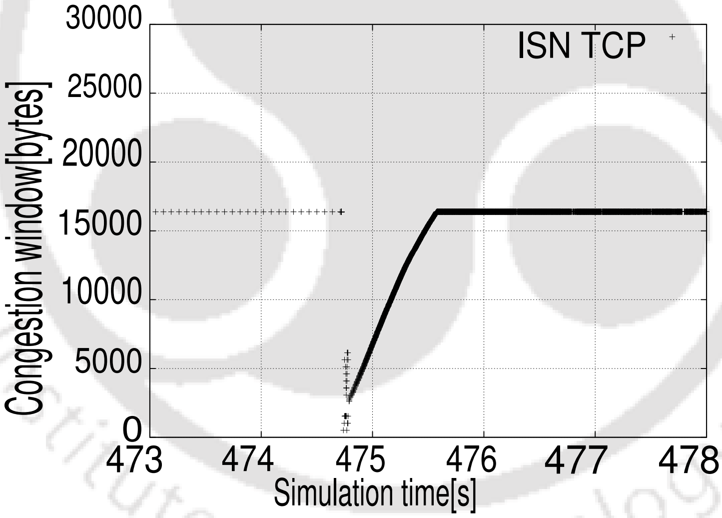

Figure 4.6: CWnd (UMTS → WLAN)

eliminate CWnd drops fully. From the simulation analysis, it has been observed that amount of retransmissions increases for ISN-TCP. In the present simulation scenario, there are 35KB of retransmissions per TCP connection. The amount of retransmission increases because ISN-TCP retransmits packets that were not acknowledged through the old-interface. Because of these increased amount of retransmissions that generates DACKs for the sender, the CWnd is dropped. It has been observed from extensive simulations that the amount of retransmission increases with the increase of TCP packet size and the

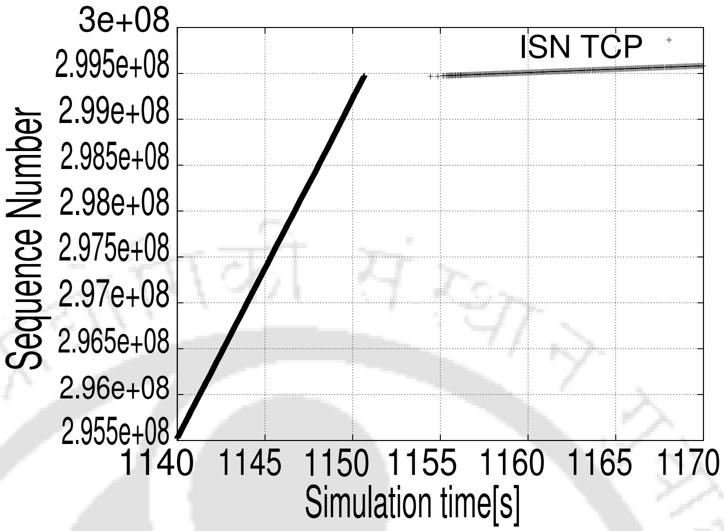

Figure 4.7: Data Sent (WLAN → UMTS)

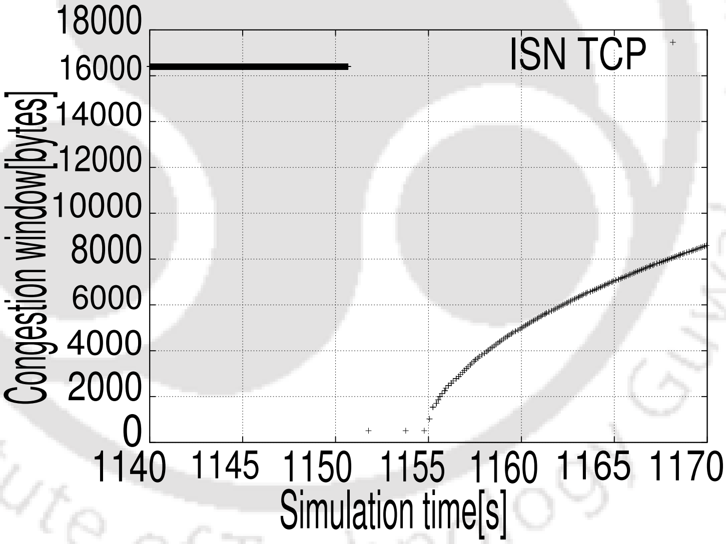

Figure 4.8: CWnd (WLAN → UMTS)

number of active TCP connections during handover.

The Handover from the WLAN to the UMTS:

The performance of ISN-TCP for the WLAN to the UMTS handover is shown in Figure 4.7 and Figure 4.8. As ISN-TCP freezes the TCP connection, it doesn't cause successive time outs as in the case of WP-TCP. However estimating the parameters after handover and freezing of connection affects the TCP performance as shown in Figure 4.7. In Figure 4.7, data receiving stops at mobile node at 1150.67 secs, and data receiving again starts at 1155.3 sec. This break in transmission is because of freezing the transmission during handover and estimating the parameters of the network.

The performance of ISN-TCP for the UMTS-WLAN vertical handover can be summarized as follows;

1. To solve the problem of the packet loss and the packet reordering at the time of the UMTS to the WLAN handover, ISN-TCP saves the sequence number of the last packet acknowledged through the UMTS interface before handover, and sends all the packets after that sequence number through the WLAN interface, once the handover gets complete. Though this can solve packet loss and packet reordering, it generates lots of duplicate transmissions. This is because, the packets which were sent through the UMTS interface before handover, but not acknowledged, are retransmitted. This large amount of retransmission causes DACKs, and the expiration of DACK threshold. This causes TCP to reset its CWnd.

2. Spurious RTOs during the WLAN to the UMTS handover are avoided in ISN-TCP by freezing the TCP parameters and estimating the new value after the handover.

To mitigate these problems of the ISN-TCP over the vertical handover framework, the next section proposes an improved variant of TCP protocols to deal with duplicate transmissions and spurious RTOs.

4.3 ISN-TCP-PLUS: Improved TCP for ISN based Handover Framework

In the proposed TCP amendment over ISN-TCP, a *handover layer* is added between the transport and the network layer, which implements the solution to improve the TCP performance. This *handover layer* is added only at the end devices. It can be noted that the handover affects mostly the TCP connection from the CN to the MN as the CN is not aware of the impending handover. The connections from the MN to the CN suffer less because the handover is initiated by the MN. That is why the modifications in TCP is reported with respect to the connection from the CN to the MN. The reverse way connection can be handled in a simpler way.

4.3.1 The Handover from the UMTS to the WLAN

In this case, DACKs are generated because of out-of-order packet delivery. TCP perceives three DACKs as congestion, and reduces the CWnd. Due to congestion control mechanism, TCP also makes unnecessary retransmissions. While transferring data from the CN to the MN, CN can receive the DACKs from the MN, which will trigger congestion control in CN. In ISN-TCP, the UMTS interface is immediately closed after the handover, and all the outstanding packets are retransmitted on the WLAN interface. This leads to unnecessary retransmission, which can be avoided. Simulation results in Section 4.1 and Section 4.2 show that there are significant number of retransmissions per TCP connection in the case of the WP-TCP and the ISN-TCP.

ISN-TCP-PLUS filters out unnecessary DACKs so that the congestion control actions are not triggered at CN during handover. The sequence of actions that are triggered by the *handover layer* of the ISN-TCP-PLUS at the MN and the CN are as follows;

1. When the MN initiates the process of handover from the UMTS to the WLAN network, there is a cross layer interaction between the MAC layer, and the *handover layer* at the MN, which sends *handover notification message* to the *handover layer* at the MN. In turn, the *handover layer* at the MN sends a handover notification to the CN.

2. On receiving the handover notification message from the MN, the CN saves the sequence number of the packet last acknowledged in *lastAcked* variable, and TCP transmission continues.

3. When the handover completes at the MN, handover completion notification message from the MAC layer is sent to the *handover layer* at the MN, which again sends a handover completion notification to the CN.

4. On receiving the handover completion notification, the *handover layer* at the CN saves the highest sequence number sent so far in *HigestSeqSent* variable. Now the *handover layer* at the CN monitors the ACKs received. If the sequence number of the ACK received at the *handover layer* lies between *lastAcked* and *HigestSeqSent*, then it is a DACK, and the ACK frame is dropped.

5. When the sequence numbers of ACKs become greater than *HigestSeqSent*, then the *handover layer* stops the filtering of the ACKs, and the normal TCP operation resumes.

As the DACKs are the wrong indicators for the network congestion in the case of the handover from the UMTS to the WLAN, the *handover layer* filters out the DACKs between $lastAcked$ and $HigestSeqSent$. TCP doesn't invoke congestion control as the DACKs are filtered out by the *handover layer*. If packets on the UMTS interface are lost permanently, then TCP will eventually time out, and retransmit those packets. Filtering period at the *handover layer* could maximum go up to the RTO in the UMTS network (RTO_{UMTS}). TCP does not immediately change to the updated RTT values of the WLAN networks on handover, because this may lead to the spurious timeouts. As DACKs are filtered, TCP perceives the same RTT as in the UMTS network. So filtering the ACKs does not cause spurious timeout at the TCP sender. If the ACKs are piggybacked, then instead of filtering the ACKs, the ACK bit of the data packet can be reset. In this method, no change to existing TCP implementations is required, and only a *handover layer* below the TCP is required to be implemented at the end devices.

4.3.2 The Handover from the WLAN to the UMTS

During the handover from the WLAN to the UMTS network, the problem is spurious RTOs. The RTO at the WLAN network (RTO_{WLAN}) is lesser than RTO_{UMTS}. The ACKs for the packets transmitted by the TCP sender in the WLAN network, just before the handover, arrive through the UMTS network. RTO perceived by the TCP sender in the WLAN network is significantly lesser than the current RTT for ACKs through the UMTS network. Therefore, TCP triggers RTOs, drops CWnd to 1, retransmits the packet, and exponentially backs off the retransmission timer. This leads into a coarse packet transmission in the period after the handover, and reduces TCP performance.

Moreover, even after the exponential back-off, multiple retransmit timeouts occur before the TCP estimates the RTT of the UMTS network (RTT_{UMTS}). In ISN-TCP, TCP connection is freezed during the handover, and is unfreezed only after the measurement of the required parameters after the handover. This affects the TCP performance as shown in section 4.2. Performance degradation by freezing the TCP connection would be more in the case of the "make before break" handover [48]. The RTT calculation method proposed in this section can be used to estimate the RTT of probable networks before the handover. It can also be used to estimate the end-to-end delay parameter of the QoS, while scanning for the available networks. In ISN-TCP, RTT calculation can only be performed by freezing the connection after the handover has taken place. WP-TCP also estimates the RTT value by the usual mechanism after triggering many RTOs. An improved version of the RTT estimation mechanism is proposed in this chapter that significantly improves the TCP performance.

ISN-TCP-PLUS uses this RTT estimation to update the TCP parameters during handover. The detailed actions performed by ISN-TCP-PLUS for the WLAN to the UMTS handover are as follows;

1. The MAC layer at the MN sends a handover notification to the *handover layer* at the MN about the impending handover.

2. The *handover layer* at the MN, on receiving the handover notification, measures the the RTT between the MN and the WLAN AP (RTT_{MN-AP}), by sending ICMP ECHO message to the current WLAN AP. Here either multiple ICMP ECHO requests can be sent, and the average can be taken, to get accurate RTT_{MN-AP}, or the *handover layer* can continuously monitor RTT_{MN-AP}, and apply TCP like smoothing of the estimated RTT.

3. The *handover layer* also sends an ICMP ECHO request to the GGSN through the UMTS interface, and measures the RTT between the MN and the GGSN ($RTT_{MN-GGSN}$).

4. After measuring RTT_{MN-AP} and $RTT_{MN-GGSN}$, the *handover layer* at the MN sends a update parameter message to the CN, with these values.

5. The CN, on receiving handover update parameter from the MN, does a cross layer interaction with the TCP, and saves the current estimated RTT (smoothed RTT) in variable $EstRTT_{WLAN}$. Then the *handover layer* estimates the $SampleRTT_{UMTS}$ by equation (4.1),

$$SampleRTT_{UMTS} = \quad EstRTT_{WLAN} - RTT_{MN-AP} + RTT_{MN-GGSN} \tag{4.1}$$

6. This gives the Sample RTT of the UMTS network. Now this can be used to calculate $EstimatedRTT_{UMTS}$ using a similar procedure as [93]. Initially the value of $Deviation_{UMTS}$ is set as half of the $SampleRTT_{UMTS}$. Then the difference between the sample RTT and the estimated RTT ($Difference_{UMTS}$) for the UMTS network can be calculated by equation (4.2),

$$Difference_{UMTS} = \quad SampleRTT_{UMTS} - EstimatedRTT_{UMTS} \tag{4.2}$$

Initially $EstimatedRTT_{UMTS} = SampleRTT_{UMTS}$. $EstimatedRTT_{UMTS}$ can be calculated using equation (4.3) as follows;

$$EstimatedRTT_{UMTS} = EstimatedRTT_{UMTS} + (\delta \times Difference_{UMTS}) \tag{4.3}$$

Here δ is a smoothing fraction between 0 and 1. From equation (4.2) and equation (4.3), the deviation for the UMTS network ($Deviation_{UMTS}$) can be calculated as follows;

$$\begin{aligned} Deviation_{UMTS} = \; & Deviation_{UMTS} + \\ & \delta \times (Difference_{UMTS} - Deviation_{UMTS}) \end{aligned} \tag{4.4}$$

Based on the estimated RTT of the UMTS network and the RTT deviation, TCP computes the timeout value as a function of $EstimatedRTT_{UMTS}$ and $Deviation_{UMTS}$, as given in equation (4.5).

$$TimeOut_{UMTS} = \mu * EstimatedRTT_{UMTS} + \phi * Deviation_{UMTS} \tag{4.5}$$

The value of μ and ϕ is calculated based on experience. μ and ϕ depends on the link quality and the link speed difference between the WLAN and the UMTS network. For the current analysis, μ is set to 1, and ϕ is set to 5.

7. By cross layer interaction between the *handover layer* and the TCP, $TimeOut_{UMTS}$ is updated in the TCP. The current retransmit timer, set to $TimeOut_{WLAN}$, is also updated according to $TimeOut_{UMTS}$ by equation (4.6) and equation (4.7).

$$diffT = TimeOut_{WLAN} - CurrRetransmitTimer \tag{4.6}$$

$$CurrRetransmitTimer = TimeOut_{UMTS} - diffT \tag{4.7}$$

8. After the updation of the above mentioned values, the *handover layer* becomes passive, and the normal TCP processing begins.

4.3.3 Estimation of congestion window during handover

During the handover from the WLAN to the UMTS network, CWnd in the WLAN network remains high compared to the UMTS network. Just after the handover, this difference in CWnd may trigger unnecessary congestion congestion control actions in the UMTS network. As TCP reduces CWnd to its minimum value, and then increases it linearly, it takes some time to TCP to adjust its CWnd to appropriate value. Similarly in the case of handover from the UMTS to the WLAN network, value of the CWnd in the UMTS network is less than value of CWnd in the WLAN network, and TCP increases CWnd linearly.Thus an estimation of appropriate CWnd for the new network just after the handover would increase the performance of TCP. The appropriate sending rate (T) of TCP is adjusted after handover using equation (4.8) as follows,

$$T = \frac{s}{R\sqrt{\frac{2p}{3}} + t_{RTO}(3\sqrt{\frac{3p}{8}})p(1+32p^2)} \tag{4.8}$$

In equation (4.8), T is in bytes/sec, s is the packet size, R is the RTT in new network, p is the steady state loss event rate, t_{RTO} is the TCP RTO value in the new network. Equation (4.9) is used to calculate the CWnd after the handover, as follows

$$CWnd = T * RTT \tag{4.9}$$

To estimate the sending rate T, as given in equation (4.8), R can be calculated by equation (4.3), and t_{RTO} can also be calculated by equation (4.5). p is the average loss event probability as defined in [85]. p can be measured continuously by the *handover layer* at the sender side, and equation (4.8) and equation (4.9) can be used to estimate the congestion window, and is updated by the *handover layer* into the TCP control block.

4.4 Simulation and Analysis

The proposed ISN-TCP-PLUS has been implemented and simulated using Qualnet-5.0.1 [87] network simulation framework. The simulation scenario is taken similar to Figure 3.2, in Chapter 3, and the network parameters are taken as described earlier in section 4.1. The proposed scheme is compared with the ISN-TCP and the WP-TCP. It can be noted that ISN-TCP already incorporates freezing concept for the WLAN to the UMTS handover, similar to freeze the TCP [54, 55] and the rate adaptation techniques for the UMTS to the WLAN handover [43–45]. So the proposed scheme is not compared explicitly with these techniques, and compared with the ISN-TCP and the WP-TCP.

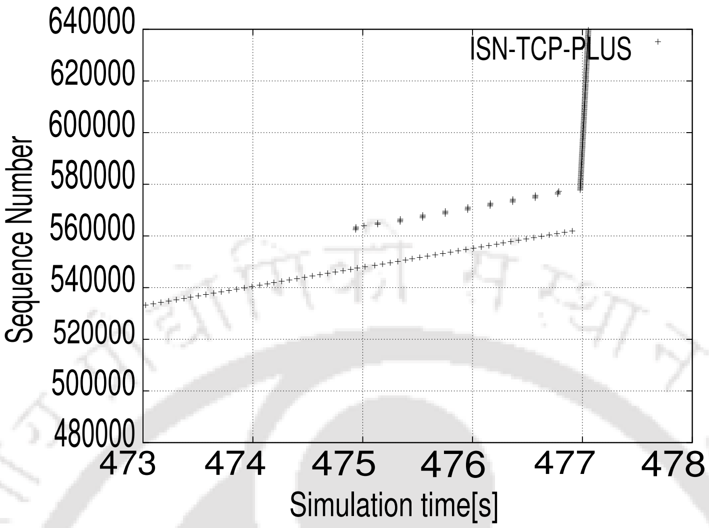

Figure 4.9: Data Sent (UMTS→WLAN)

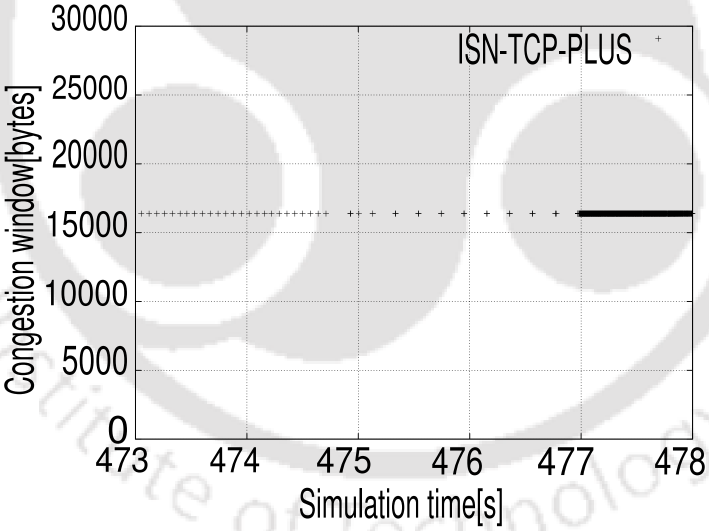

Figure 4.10: CWnd (UMTS→WLAN)

4.4.1 Packets Sent and CWnd Variation During Handover

This subsection provides the performance of the ISN-TCP-PLUS with respect to the data packets sent and the CWnd variations during handover. The simulation results for both the UMTS to the WLAN handover and vice-versa are explained next.

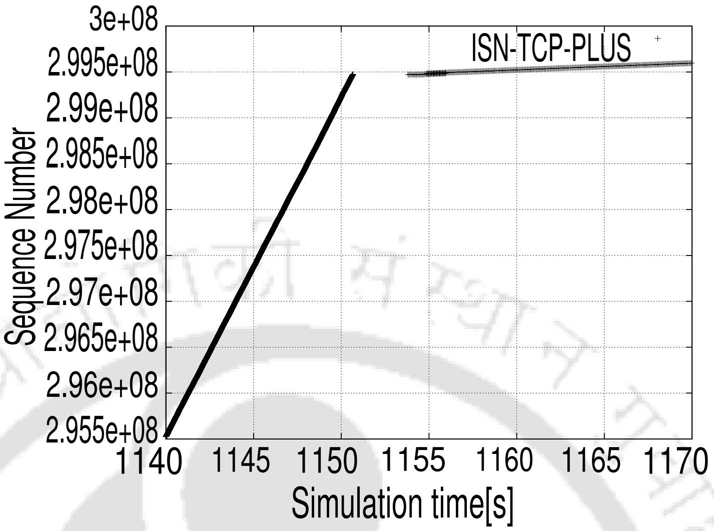

Figure 4.11: Data Sent (WLAN→UMTS)

UMTS to the WLAN Handover

The simulation results for the UMTS to the WLAN handover is shown in Figure 4.9 and Figure 4.10. The handover is started at 474.5 seconds, and is completed at 474.8 seconds. From Figure 4.9, both the higher sequence number packets from the WLAN interface and the lower sequence number packets from the UMTS interface are forwarded. This is because the UMTS interface is not closed immediately after handover. However, as DACKs are filtered out based on handover notifications, TCP does not invoke congestion control actions. In this way unnecessary retransmissions and CWnd variations are avoided, as shown in Figure 4.10. Effectively, even after handover, data rate is guided by the UMTS network for some duration. It has been observed that amount of packet retransmissions is considerably lower compared to the WP-TCP and the ISN-TCP.

WLAN to the UMTS Handover

The simulation results for the WLAN to the UMTS handover is shown in Figure 4.11 and Figure 4.12. In the ISN-TCP-PLUS, the RTT value calculated using the procedure mentioned in section 4.3, is updated in TCP control block.This prevents the spurious RTOs from occurring, and improves the performance. As shown in the Figure 4.11, data receiving by mobile node stops at 1150.67 secs, and again continues from 1153.80 secs. This break in transmission is due to underlying handover “break before make” scheme. It can be seen from Figure 4.12, there is no CWnd drops after handover.

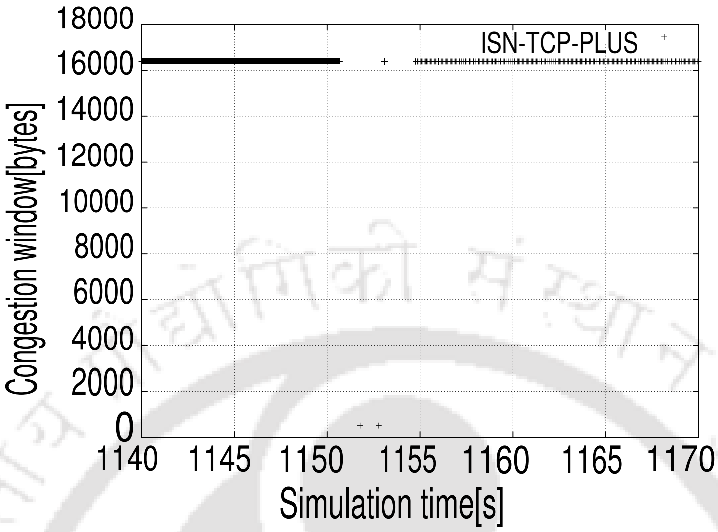

Figure 4.12: CWnd (WLAN→UMTS)

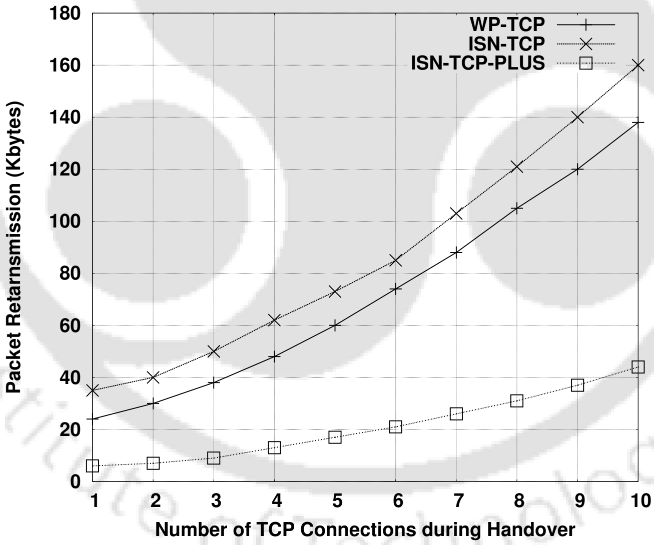

Figure 4.13: Amount of Retransmission for the UMTS to the WLAN Handover

4.4.2 Amount of Retransmission for the UMTS to the WLAN Handover

The problem for the UMTS to the WLAN handover is amount of unnecessary retransmissions and expiration of the DACK threshold. The improvement of ISN-TCP-PLUS with respect to amount of retransmissions is shown in Figure 4.13. Amount of retransmission is considerably less compared to the WP-TCP and the ISN-TCP. In case of the ISN-TCP-PLUS, the only packets which are lost during handover is retransmitted through

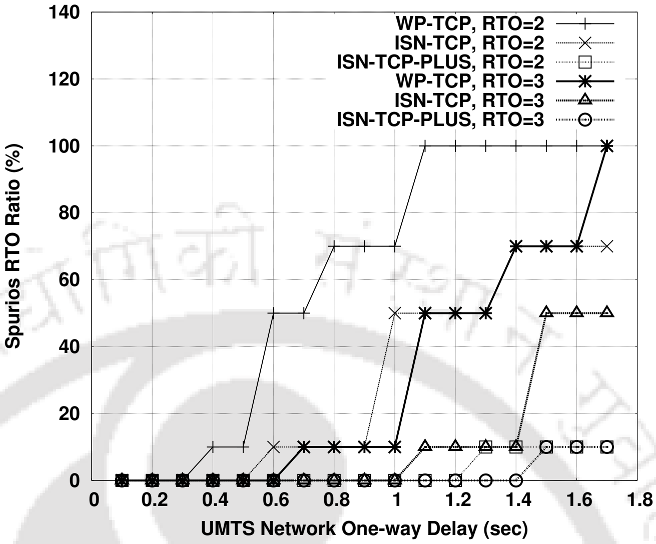

Figure 4.14: Spurious RTOs for the UMTS to the WLAN Handover

the WLAN interface. Amount of retransmission is very high for the ISN-TCP, because the ISN-TCP explicitly retransmits all previously transmitted packets through the UMTS interface during the handover, and the UMTS interface is immediately closed after the handover.

4.4.3 Spurious RTOs during the WLAN to the UMTS Handover

The problem while handing over from the WLAN to the UMTS network is the spurious RTOs. Figure 4.14 presents the percentage of two consecutive and three consecutive spurious RTOs, as a function of the UMTS network one way channel delay. Maximum CWnd is taken as 10 packets which is equal to bandwidth delay product (BDP). The lowest delay for the occurance of two or three consecutive spurious RTOs is considerably higher for the ISN-TCP-PLUS as compared to the WP-TCP and the ISN-TCP. The spurious RTOs occur when the RTO is less than the maximum time between the arrival of the last ACK from the WLAN network and the first ACK from the UMTS network. The RTO estimation procedure as proposed for ISN-TCP-PLUS estimates the new RTT and RTO for the UMTS network immediately after the handover, and TCP parameters are updated accordingly. Thus ISN-TCP-PLUS avoids spurious timeouts. It can be seen from the figure that two consecutive spurious RTOs occur for ISN-TCP-PLUS when the UMTS one way delay is more than 1.3 seconds, and three consecutive spurious RTOs occur when the one-way UMTS delay is more than 1.5 seconds. The estimation procedure

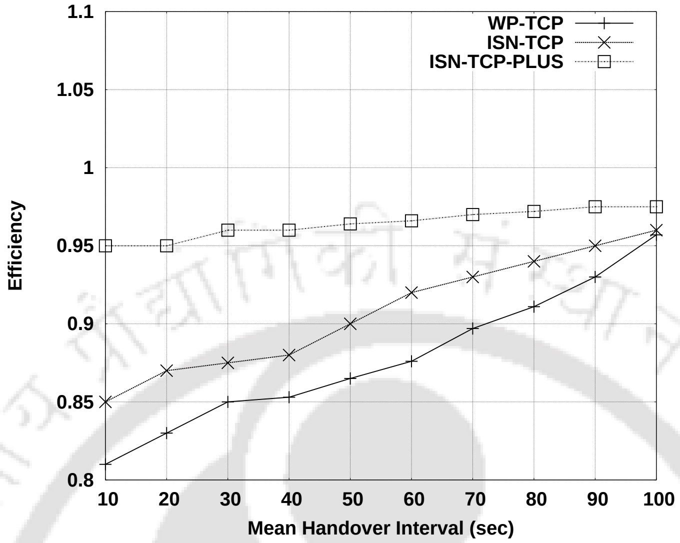

Figure 4.15: TCP Efficiency

fails for high UMTS delay because while estimating initial $Deviation_{UMTS}$ is taken as zero, whereas actual $Deviation_{UMTS}$ is very high. Therefore, the convergence requires considerable amount of rounds, before which the RTOs occur. However, this much of high one way delay for the UMTS network never occurs in practice.

4.4.4 TCP Efficiency

TCP efficiency is defined as the ratio of the number of packets transmitted successfully to the actual number of packets transmitted. In Figure 4.15, the efficiency for TCP flow is shown with respect to mean handover interval. Mean handover interval is defined as the average time between two consecutive handover. It can be seen from the figure that the efficiency of ISN-TCP-PLUS is significantly higher compared to the ISN-TCP and the WP-TCP, when mean handover interval is very high. The figure shows that the proposed ISN-TCP-PLUS is very adaptive with frequent handover.

4.5 Summary

This chapter provides an improved TCP variant for the vertical handover between the UMTS and the WLAN networks using the ISN based framework. The shortcomings of the WP-TCP is analyzed using the simulation results. It has been observed that the main problem during the handover from UMTS to WLAN network(slow to a fast network) is the unnecessary retransmissions and that from WLAN to UMTS handover(fast to a slow network) is the spurious RTOs. The proposed TCP variants, namely the ISN-TCP and ISN-TCP-PLUS, use an estimation mechanism for measurement of the new RTT and the RTOs after the handover thereby avoids spurious RTOs during handover from WLAN to UMTS network. The unnecessary retransmissions during UMTS to WLAN handover is avoided through the filtering of unnecessary DACKs. The sending rate for the TCP is estimated after the handover is over, and the CWnd is updated accordingly so that TCP can rapidly adopt to the new link characteristics after the handover process gets completed. Simulation results confirm that ISN-TCP and ISN-TCP-PLUS perform considerably better than WP-TCP.

Ensuring QoS for the mobile users during vertical handover between IEEE 802.11 WLAN and data network provided by UMTS is another key requirements for seamless mobility and transfer of existing connections from one network to another. QoS fulfillment is a complex problem and requires participation of both the mobile users as well as the connection networks. The QoS assurance criteria for existing connections can be affected by fluctuations of data rates when a user moves from the high speed WLAN network to the low speed UMTS network, even in the presence of another WLAN network in its vicinity. This can happen if the alternate WLAN network is highly loaded. Therefore handover from a high speed network to a low speed network should be avoided, whenever possible. The next chapter proposes a QoS based handover procedure that prioritizes the existing connection over the new connections as a result of which the rate fluctuations due to handover can be avoided if there exist another WLAN network in the range of the mobile user.


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Chapter 5

Vertical Handover over Intermediate Switching Framework: Assuring Service Quality for Mobile Users

An efficient handover mechanism between hybrid networks is becoming a critical issue due to data rate differences among the underlying networks. Various handover methods for inter-networking of heterogeneous networks like UMTS and WLAN have been proposed in literature which aim at providing seamless handover from one network to another, as discussed in Chapter 2. However most of the existing handover schemes use Received Signal Strength Identifier (RSSI) as the metric for handover initialization decision. RSSI based handover is not a good solution because of the following reasons,

- RSSI based handover decision may result in a premature handover between IEEE 802.11 and UMTS [65], even though the achievable data rate from the IEEE 802.11 network for the mobile node is much higher than the one it may get from UMTS network.

- In case of heterogeneous networks, divergent networks may have dissimilar values of channel coding loss factor, noise and interference power which makes RSSI incomparable for different wireless technologies.

- Proper load balancing between different network is required to design effective call admission control mechanism.

Then we have these schemes which are based on Signal to Interference Ratio(SINR) which is a better metric than RSSI [67]. Experimental results show that SINR-based handover methods results in better throughput than RSSI-based handover ones but it still doesnot consider any QoS parameters like bandwidth, delay, jitter etc.

Therefore, a better metric is required for making vertical handover decisions. This chapter proposes a QoS based handover mechanism over the ISN based framework as proposed in Chapter 3. UMTS network provides more coverage compared to any IEEE 802.11 WLAN network. An umbrella like topology is considered where IEEE 802.11 networks create coverage holes under the scope of an UMTS network. Whenever a mobile node enters under the coverage of an IEEE 802.11 WLAN network, it is preferable to switch the connection from the UMTS network to the IEEE 802.11 WLAN network. The handover decision is taken cooperatively by the mobile node and its current point of attachment based on QoS requirement. The UMTS network is available all the time. Therefore, if the QoS of the current WLAN network where the mobile node is attached goes down, it is always preferable to handover to another IEEE 802.11 WLAN, if available, than to the UMTS network. This is because sudden performance degradation can be observed if the mobile node is handed over to the UMTS network from an IEEE 802.11 WLAN network. Further, existing connections are preferred over new connections. This chapter considers a per-node QoS requirement where the QoS for every mobile user is based on the economic subscription with the service provider. The scheme proposed in this chapter has following contributions;

- A per-node QoS differentiation strategy is proposed where mobile users can avail network service based on their economic subscription with the service provider.

- The new connections are admitted to the network if sufficient bandwidth is available after allocating required bandwidth to all the existing connections. To maintain consistency in QoS, existing connections are preferred over new connections.

- A pre-handover bandwidth reservation scheme is proposed to reserve bandwidth at alternate connection points to avoid QoS degradation during handover. Further, pre-handover bandwidth reservation helps to prioritize the handover from one IEEE 802.11 network to another IEEE 802.11 network over the handover from UMTS to IEEE 802.11 network.

- The effectiveness of the proposed scheme is justified using simulation results.

The rest of the chapter is organized as follows. The proposed mechanism for per-node QoS and bandwidth reservation during vertical handover has been discussed in section 5.1. The simulation results are reported in section 5.2. Finally, section 5.3 concludes the chapter.

5.1 QoS based handover and Bandwidth Reservation

In this chapter, per-node QoS requirements is considered in terms of bandwidth, delay and jitter. The handover decision is based on SINR value along with the QoS requirements. The QoS parameters are prioritized based on their corresponding weight. For this purpose, a QoS parameter is defined, called *Normalized QoS Value*(NQV) which computes the QoS requirement for a mobile node. The NQV function for a mobile node is defined as:

$$NQV = \sum_{i}^{k} (w_i \times N \times qos_i) \tag{5.1}$$

where qos_i is the i^{th} QoS parameter, w_i is the corresponding weight and N is the normalization factor. The 'Normalization factor' is a logarithmic function which normalizes QoS parameters into comparable value in cases of heterogeneous networks. The weights associated with each QoS parameter allows to control the effect on the NQV for any amount of the individual change. It can be noted that the weight values for individual QoS parameters are assigned by the service provider and the mobile nodes use required authentication mechanism similar to [94] so that the end-users will not be able to alter the weights for individual QoS parameters. The APs periodically broadcasts association beacons to inform the mobile nodes about the existence of corresponding IEEE 802.11 network. A mobile node can be under the coverage of more than one IEEE 802.11 APs. The following terms are used to design the handover procedure;

Definition 5.1. *Connection Threshold is defined as the lower limit of the SINR value above which a mobile node can get connected with the corresponding AP in the IEEE 802.11 network.*

Definition 5.2. *Let a mobile node q is under the coverage of a network $\aleph$. Then the network $\aleph$ is called available to mobile node q if the SINR value calculated from the association beacons broadcast by the AP of that network is more than connection threshold.*

It can be noted that the UMTS network is always available to all the mobile nodes. The handover decision is taken in a cooperative way between the mobile node and the MSF-LER of the current point of attachment (either GGSN/MSF-LER or AP/MSF-LER). To meet consistency in specific QoS requirements, the existing connections in IEEE 802.11 WLAN are prioritized over the new connections. The pre-handover actions performed by the mobile node and the AP/MSF-LERs are described in following subsections.

5.1.1 Pre-handover Actions Performed by Mobile Nodes

Following steps are performed by a mobile node prior to deciding handover to another network due to non satisfiability of NQV value.

1. Each mobile node periodically measures the available networks to connect to.
2. Each mobile node also measures its experienced NQV value (NQV_{exp}) periodically, according to equation (5.1).
3. The mobile node sends the available network information to the MSF-LER of the current point of attachment. This way the GGSN/MSF-LER and AP/MSF-LERs get to know the information about available networks for all the mobile nodes connected with it. This helps redirecting the mobile nodes to another network if either there exists a better network or the NQV value falls down below the threshold.
4. The mobile node also sends the measured NQV value of the current network to the MSF-LER of its current point of attachment. This way the GGSN/MSF-LER and the AP/MSF-LERs can be made aware of the current network conditions. The MSF-LERs make an average of the NQV values obtained from all the mobile nodes connected with it to get an estimate of network condition.

5.1.2 Pre-handover Actions Performed by AP/MSF-LERs

Let $BW(m)$ denotes total bandwidth capacity of the network under AP/MSF-LER m, $BW_{used}(m)$ denotes the used bandwidth and $BW_{avail}(m)$ denotes available bandwidth of the network under AP/MSF-LER m. Let $\triangle t$ denotes the periodicity of the bandwidth measurement. $\mathbb{M}_m$ denotes the set of mobile nodes attached with the AP/MSF-LER m. $\lambda_m^q(t, t + \triangle t)$ denotes the average data transmission rate between mobile node $q \in \mathbb{M}_m$ and AP/MSF-LER m, in the period $(t, t + \triangle t)$. Every AP/MSF-LER also maintains a database for the mobile nodes connected with it. Every entry of the database contains the tuple $(q, NQV_{exp}(q), < NET_q >)$ where q is the mobile node identifier, $NQV_{exp}(q)$ is the NQV value experienced by the mobile node and $< NET_q >$ is the set of network identifiers which are available for mobile node q. To meet specific QoS requirements in

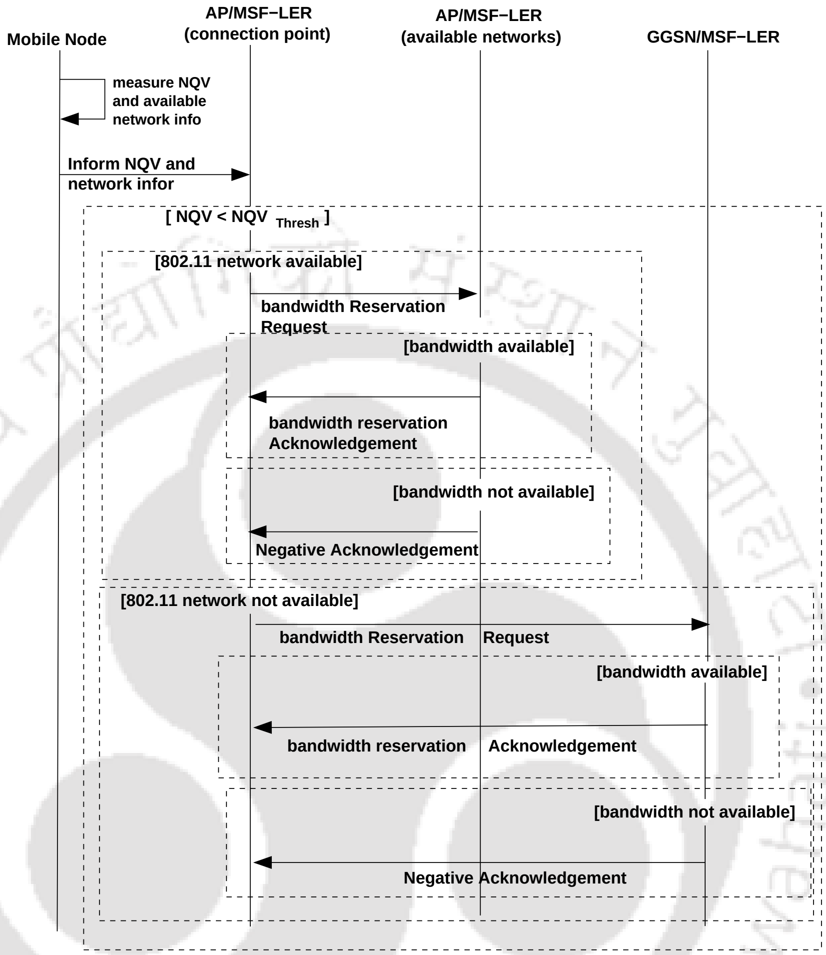

Figure 5.1: Pre-Handover actions at mobile nodes and MSF-LERs

terms of NQV, the handover from one IEEE 802.11 WLAN to another IEEE 802.11 WLAN is prioritized over the handover from UMTS to IEEE 802.11 WLAN network. For this purpose, the AP/MSF-LERs reserve bandwidth to the neighboring networks for the mobile nodes connected with them. The following steps are performed by the AP/MSF-LERs periodically,

1. Each AP/MSF-LER m periodically measures the used bandwidth at link layer as follows;

$$BW_{used}(m) = \sum_{i \in \mathbb{M}_m} \lambda_m^i(t, t + \triangle t) \tag{5.2}$$

   It also measures available bandwidth as follows;

$$BW_{avail}(m) = BW(m) - BW_{used}(m) \tag{5.3}$$

2. On receiving the neighboring network information and NQV value from mobile node q, MSF-LER updates the NQV value and neighboring network information for this mobile node in its database corresponding to the tuple $(q, NQV_{exp}(q), < NET_q >)$.

3. Let $NQV_{min}(q)$ denotes minimum NQV requirement for mobile node q as set up by the service provider based on the economic subscription plan. Let $NQV_{Thresh}(q)$ $(> NQV_{min}(m))$ denotes the NQV threshold for mobile node q. If the NQV value for mobile node q drops down below $NQV_{Thresh}(q)$, this indicates that the mobile node q may experience QoS degradation in near future. When $NQV_{exp}(q) \leq NQV_{Thresh}(q)$, the AP/MSF-LER chooses one IEEE 802.11 WLAN network from the neighboring network information for mobile node q, sends a bandwidth reservation request to the corresponding AP/MSF-LER of that IEEE 802.11 WLAN network, and waits for the acknowledgment from that AP/MSF-LER. If no IEEE 802.11 network is available in the neighboring network information and the mobile node is currently connected with an IEEE 802.11 network, then the bandwidth reservation request is forwarded to GGSN/MSF-LER.

4. Similar action is performed if the SINR value observed at the mobile node for its current point of attachment drops down below $SINR_{TT}$, where $SINR_{TT}$ is (Connection Threshold $+ \chi$). χ is the tolerance factor. The value of χ is decided based upon the fact that how quickly the AP/MSF-LER should reserve bandwidth for a possible handover.

5. On receiving the bandwidth reservation request, an MSF-LER checks whether the reservation is possible from its available bandwidth calculated using equation (5.3). If the bandwidth can be reserved, it forwards a bandwidth reservation acknowledgment to requesting AP/MSF-LER and a reservation expiry timer T_{RES} is triggered. If the MSF-LER can not reserve bandwidth for that request, a negative acknowledgment is sent.

6. On receiving bandwidth reservation acknowledgment, the requester AP/MSF-LER also starts an expiry timer T_{REQ}. The value of T_{REQ} is set equals to the value of T_{RES}.

7. On receiving a negative acknowledgment, the requester AP/MSF-LER chooses another AP/MSF-LER from $< NET_q >$. If no other AP/MSF-LERs are available in $< NET_q >$ and the mobile node is currently connected with an IEEE 802.11 network, then the bandwidth reservation request is forwarded to GGSN/MSF-LER.

8. On expiry of the timer T_{RES}, reserving MSF-LER frees up the reserved bandwidth and this automatically gets added up to available bandwidth at that MSF-LER. At the requester, on expiry of T_{REQ}, if $NQV_{exp}(q)$ is still less than $NQV_{Thresh}(q)$, the bandwidth reservation request is made again.

The sequence diagram for pre-handover actions performed by the mobile nodes and MSF-LERs are shown in Figure 5.1. In the proposed mechanism, bandwidth is reserved a priori even before the critical reduction in QoS values at the mobile nodes. There are two reasons for this,

- During handover time, bandwidth may not be available at the MSF-LER of the other IEEE 802.11 networks to meet the QoS requirement for that mobile node.
- The bandwidth reservation option is applicable for the MNs attached with AP/MSF-LERs only. Bandwidth is not reserved for the MNs initially associated with GGSN/MSF-LERs. This prioritizes the handover from one IEEE 802.11 network to another IEEE 802.11 network, over the handover from UMTS network to IEEE 802.11 networks.

5.1.3 Pre-Handover Actions at GGSN/MSF-LER

On receiving the bandwidth reservation request from AP/MSF-LERs, GGSN/MSF-LERs reserve bandwidth for the mobile nodes to maintain QoS consistency. However, GGSN/MSF-LERs are not allowed to send bandwidth reservation request at AP/MSF-LERs. Whenever a new mobile node wants to join in the UMTS network, if sufficient bandwidth is not available at GGSN/MSF-LER to meet QoS requirements, the connection request is dropped.

5.1.4 Handover Actions at Mobile Nodes

The handover is initiated at the mobile node q if $NQV_{exp}(q) \leq NQV_{min}(q)$. Following actions are performed during handover,

1. The mobile nodes send a handover request message to the MSF-LER at the current point of attachment for getting the information about bandwidth reservation.
2. The MSF-LER of the current point of attachment replies back with a handover response message that contains the bandwidth reservation information.

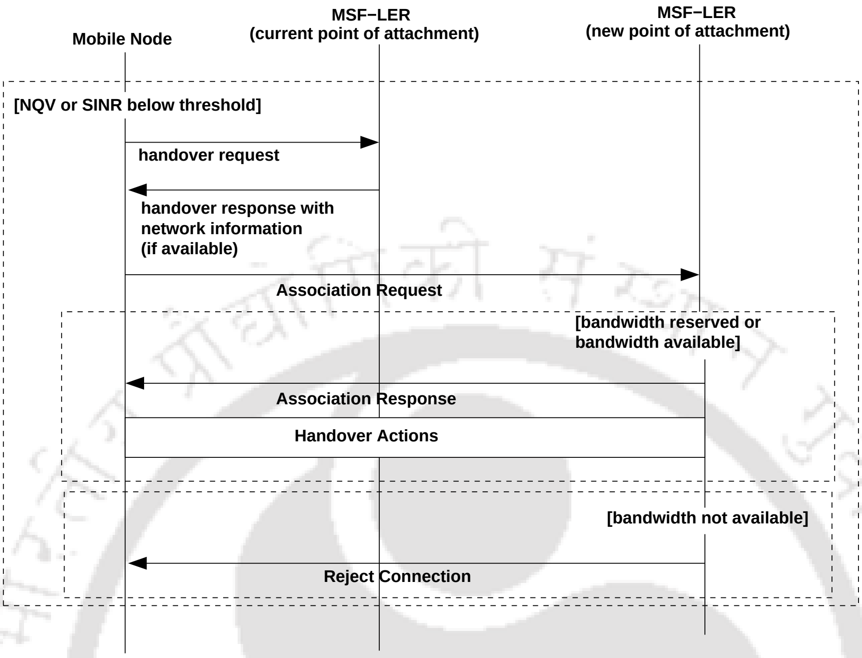

Figure 5.2: Handover actions at mobile nodes and MSF-LERs

3. On receiving the response from the MSF-LER of the current point of attachment, the mobile nodes initiate the handover and send association request message to that MSF-LER.

5.1.5 Handover Actions at MSF-LERs

Following actions are performed at the MSF-LERs during handover,

1. On receiving the association request message, the MSF/LER checks for bandwidth reservation for this mobile node. If there is reservation within the timer interval T_{RES} as discussed in subsection 5.1.2, then the request is accepted and further handover process is initiated.

2. If there is no reservation, then available bandwidth is checked using equation (5.3). If there is sufficient available bandwidth then request is accepted and further handover process is initiated.

3. If there is no available bandwidth, then the request is dropped.

The sequence diagram for handover actions at mobile nodes and MSF-LERs have been shown in Figure 5.2. The handover is unsuccessful if the required bandwidth is available

Table 5.1: Scenario Parameters

Parameter	**Value**
UDP Traffic type	CBR
TCP Traffic type	FTP
Mean CBR Data Rate	1Mbps
Mean CBR Packet Size	250 bytes
Mean CBR Packet Interval	2ms
Mobile Node Speed	1.2m/s
PDP Context Max Idle Time	45s
Registration Lifetime	20s
Max Registration retries	3
Registration retry interval	3s
UMTS Maximum Bandwidth	2 Mbps
IEEE 802.11 Maximum Bandwidth	11 Mbps

neither at AP/MSF-LER nor at GGSN/MSF-LER and the connection is dropped.

5.2 Simulation Results

The proposed scheme is implemented and simulated using Qualnet-5.0.1 [87] network simulator. The ISN framework is implemented with one UMTS network and ten overlapped IEEE 802.11 network under the UMTS network coverage. The simulation scenario consists of over 100 nodes, out of which some nodes are static and some nodes are mobile. All the mobile nodes communicate with the corresponding node which is connected with the intermediate switching network. The simulation parameters used are reported in Table 5.1. Data rate is taken sufficiently high to analyze the performance of the scheme at high load. CBR traffic is generated based on a log-normal distribution with mean packet size as 250 bytes and inter-arrival packet time of 2 ms. Log-normal distribution correctly captures the self-similar nature of network traffic [95].

The metrics used to evaluate the proposed QoS based handover scheme are defined as follows;

Definition 5.3. *Call Blocking Probability can be defined as the probability of blocking new connections due to not availability of sufficient bandwidth. The call blocking probability*

(P_b) can be calculated as;

$$P_b = \frac{Number\ of\ new\ connections\ blocked}{Total\ number\ of\ connections\ blocked/dropped} \tag{5.4}$$

Definition 5.4. *Call Dropping Probability can be defined as the probability of dropping existing connections due to unavailability of sufficient bandwidth. The call dropping probability (P_d) can be calculated as;*

$$P_d = \frac{Number\ of\ existing\ connections\ dropped}{Total\ number\ of\ connections\ blocked/dropped} \tag{5.5}$$

It can be noted that $P_b + P_d = 1$.

Definition 5.5. *Let $\mathbb{M}$ denotes set of all mobile nodes in a network. Let λ_i be the average throughput for i^{th} mobile node. Proportional Fairness Index (FI_{prop}) for the network can be defined as follows;*

$$FI_{prop} = \sum_{\forall i \in \mathbb{M}} (NQV_i \times \lambda_i) \tag{5.6}$$

Where NQV_i is the normalized QoS value for mobile node i that denotes the priority for corresponding mobile node.

In the simulation setup, the QoS parameters that are considered during NQV calculation are SINR measurement at the mobile node's interface, the interface queue size at the mobile node[1], the delay to transmit a packet from the mobile node to the MSF-LER (AP or GGSN), and the available bandwidth at the MSF-LER (AP or GGSN). In the current scenario, all these parameters are given equal weight, and the normalization factor is calculated as $1/qos_i^{max}$, where qos_i^{max} is the maximum possible value of the i^{th} QoS parameter in the present scenario. Every mobile node calculates these QoS parameters through periodic beaconing at both the interfaces (UMTS and IEEE 802.11).

5.2.1 Call blocking and call dropping probabilities

Figure 5.3 shows the call blocking probabilities vs average per connection traffic load in the network. It can be seen from the figure that call blocking probability for RSSI based handover without any bandwidth reservations is lower than call blocking probability for QoS based handover with bandwidth reservations. Figure 5.4 shows call dropping probability of existing roaming connections vs per connection average traffic

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[1] The interface queue size gives an measurement of the network congestion. If the interface queue size is large, it indicates that the network is congested.

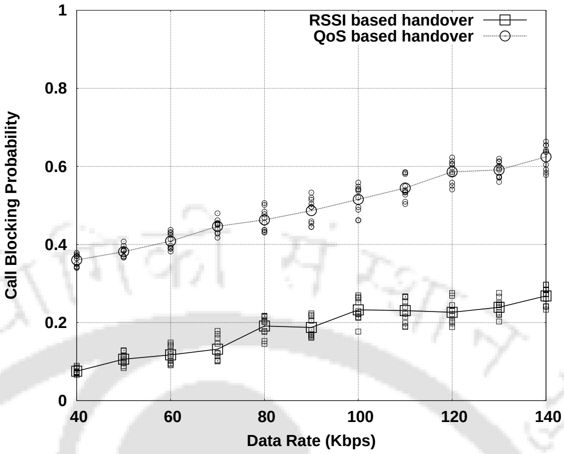

Figure 5.3: Call Blocking Probability

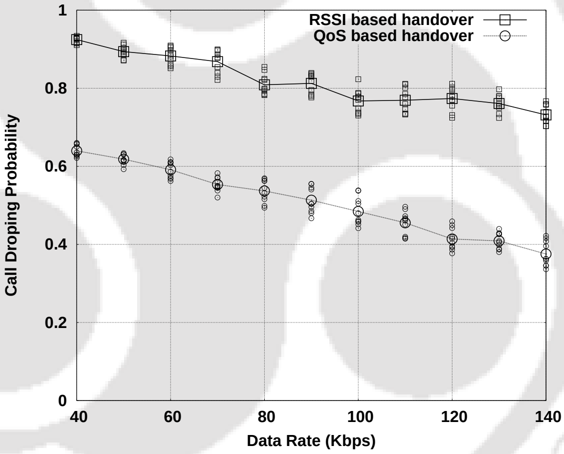

Figure 5.4: Call Dropping Probability

load. Call dropping probabilities are lower for QoS based handover compared to RSSI based handover. Because of the pre-handover bandwidth reservation, existing connections are prioritized over new connections. So in the proposed scheme new connections are dropped if there is no sufficient bandwidth available to meet specific QoS requirement. However, the connection drop for existing mobile users is significantly less in the proposed scheme.

5.2.2 Handover Latency for the QoS based Handover

A number of simulations were carried out to study the effect of the proposed QoS based handover method on the behavior of real time CBR (UDP) traffic with respect to the

Table 5.2: Handover Latency: UMTS to IEEE 802.11

Handover Metric	**UMTS to 802.11 (Seconds)**	
	1Mbps	2Mbps
Layer 2 Handover Latency	0.0012	0.0009
Layer 3 Handover Latency (Includes Bandwidth Reservation)	0.0097	0.0099
Packet Loss	0	0

Table 5.3: Handover Latency: IEEE 802.11 to UMTS

Handover Metric	**802.11 to UMTS (Seconds)**	
	1Mbps	2Mbps
Layer 2 Handover Latency	0.0064	0.0064
Layer 3 Handover Latency (Includes Bandwidth Reservation)	0.0163	0.0142
Packet Loss	6	9

Table 5.4: Handover Latency: IEEE 802.11 to IEEE 802.11

Handover Metric	**802.11 to 802.11 (Seconds)**	
	1Mbps	2Mbps
Layer 2 Handover Latency	0.0033	0.0029
Layer 3 Handover Latency (Includes Bandwidth Reservation)	0.00112	0.0101
Packet Loss	4	3

layer 2 handover duration, layer 3 handover duration that includes the time for bandwidth reservation and the end-To-end delay for the CBR traffic before and after the handover. The results are summarized in Table 5.2 to Table 5.4, and Table 5.5. Table 5.2 to Table 5.4 show the handover latency for both 1Mbps and 2Mbps CBR data rate. When the handover occurs, the packets which are in transit get lost. In the tables, the layer 3 handover

Table 5.5: Average End-To-End Delay for 1Mbps CBR (in Seconds)

	UMTS to 802.11	**802.11 to UMTS**	**802.11 to 802.11**
Before Handover	0.0219	0.0056	0.0056
After Handover	0.0057	0.0328	0.0057

latency gives the duration starting from the initiation of bandwidth reservation, to the actual handoff took place, and the traffic flow gets started. The layer 2 handoff latency reports the actual time required for the handover. As discussed earlier, in the ISN based framework, once the mobility binding is over, the packets are forwarded through the new path in the new interface. The simulation results have shown that during the handoff from UMTS to IEEE 802.11 network, the layer 3 handover duration is equal to the time required for completing of the mobility binding update, starting from the bandwidth reservation (≈ 97 ms for 1 Mbps CBR). There is also no packet loss during the handoff as it continues to receives data packets on its UMTS interface while the mobile node scans for a suitable AP/MSF-LER.

Table 5.3 shows the handover metrics for IEEE 802.11 to UMTS network. The layer 3 handover latency is a bit high in this situation (≈ 163 ms for 1 Mbps CBR) because of the extra time required to scan for alternate IEEE 802.11 APs during the bandwidth reservation procedure. If no IEEE 802.11 network is found or there is no sufficient bandwidth available at the neighbor IEEE 802.11 networks, only then the mobile node switches to the UMTS network. Table 5.4 shows that the handover latency for handoff to one IEEE 802.11 from another IEEE 802.11 network is at around 112 ms for 1 Mbps CBR traffic. If sufficient bandwidth is available in the neighboring IEEE 802.11 networks, the bandwidth reservation in this scenario takes less time compared to the previous scenario (from IEEE 802.11 to UMTS handover).

From the results shown in Table 5.5, it can be noticed that the end-to-end delay undergoes a sudden change when the handoff occurs between UMTS and IEEE 802.11 networks. This is because the packets have to traverse more number of nodes in the UMTS network than the WLAN network, and hence experience greater delays in the UMTS network. This change in the end-to-end delay can lead to jitter during the handoff and can affect audio/video applications. That is why, to assure QoS guarantee to the existing connections, handover from one IEEE 802.11 network to another IEEE 802.11 network is preferred over handover between UMTS and IEEE 802.11 networks.

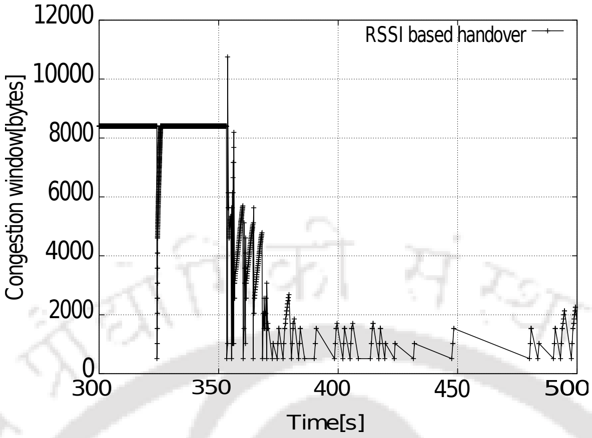

Figure 5.5: TCP congestion window in RSSI based handover (Existing Connections)

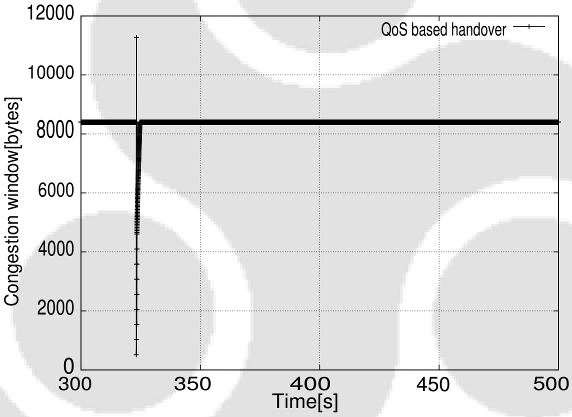

Figure 5.6: TCP congestion window in QoS based handover (Existing Connections)

5.2.3 TCP congestion window

The TCP variant, ISN-TCP-PLUS as discussed in the previous chapter, is used here to evaluate the TCP performance for both QoS based handover and the RSSI based handover. TCP congestion window gives a correct depiction of congestion and QoS satisfiability of the mobile nodes for TCP connections. In the present scenario, the TCP improvements proposed in [61] has been used to evaluate the performance. To show the effect of the proposed QoS based handover on TCP connections, two scenarios have been considered. Let *'X'* be an AP/MSF-LER. There are a few numbers of already existing connections with X, and some connections which are handed over to X from other MSF-LERs. The connections which are already there are termed as *"Existing Connections"* and the connections which are handed over to X are termed as *"Roaming Connections"*. Figure 5.5

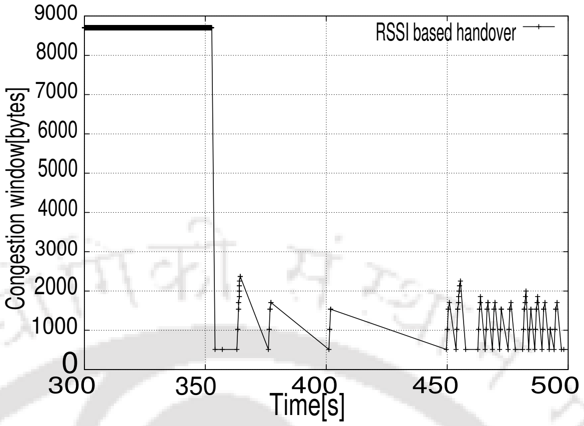

Figure 5.7: TCP congestion window in RSSI based handover (Roaming Connections)

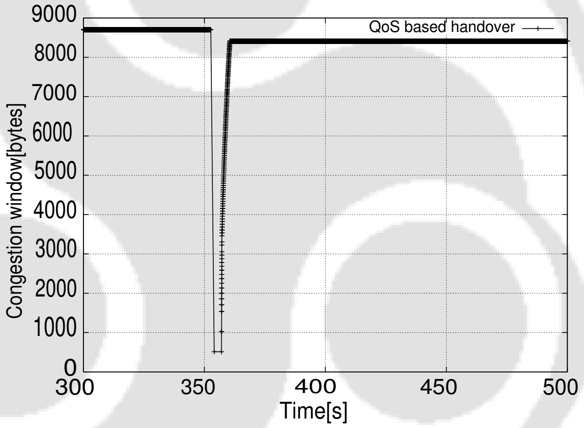

Figure 5.8: TCP congestion window in QoS based handover (Roaming Connections)

shows TCP congestion window of an existing connection for RSSI based handover scheme. It can be observed from the figure that the TCP congestion window drops very frequently for RSSI based handover scheme. Frequent drops in TCP congestion window implies the inability of TCP connections to adopt the variability in the network due to frequent handover. Figure 5.6 shows TCP congestion window of an existing connection for the proposed QoS based handover. It can be seen from the figure that TCP connections quickly adopts the variability in the network for the proposed scheme.

Similar situation occurs for roaming connections during handover, as shown in Figure 5.7 and Figure 5.8. The handover occurs at 350 sec. For the RSSI based handover scheme, the TCP connections cannot adopt the variability in the network, and TCP congestion window drops frequently. For the proposed QoS based handover, TCP

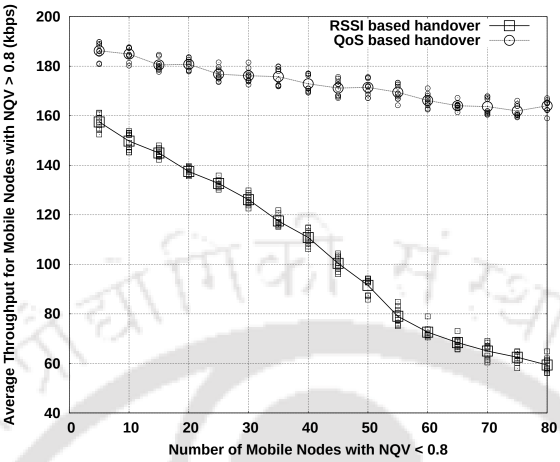

Figure 5.9: Average Throughput for High NQV Mobile Nodes

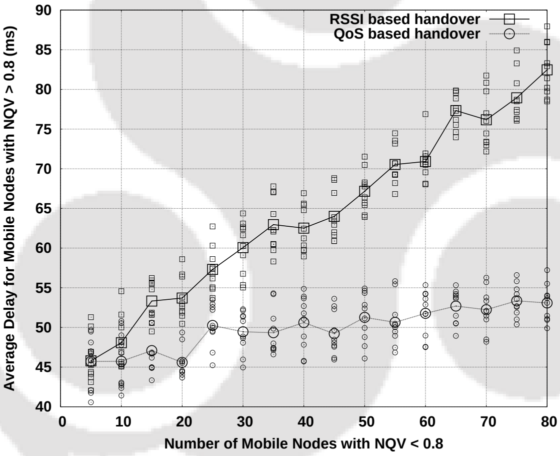

Figure 5.10: Average End to End Delay for High NQV Mobile Nodes

congestion window is steadily maintained after the handover. It can be noted that the drop in TCP congestion window at 352 sec in Figure 5.8 is due to the latency for handover from one IEEE 802.11 network to another IEEE 802.11 network. After the handover gets completed, the TCP congestion window is restored to its original value and TCP connection continues smoothly.

5.2.4 Throughput, delay and fairness in bandwidth reservation

NQV value for a mobile node depicts the priority of that node. To show the effect of throughput, delay and fairness over the high priority mobile nodes, ten mobile nodes are considered with $NQV > 0.8$, which are called high priority nodes. The graphs are plotted

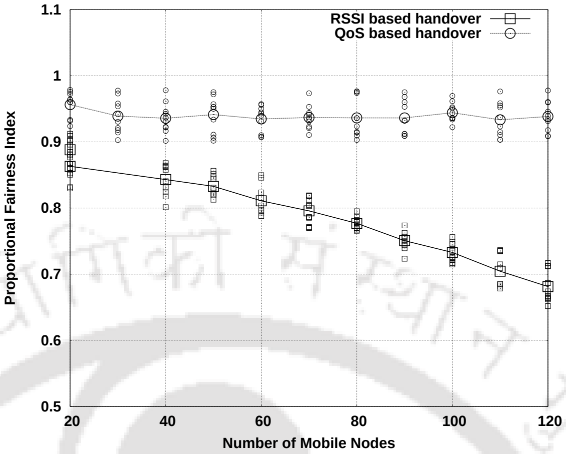

Figure 5.11: Proportional Fairness Index

by varying the number of mobile nodes with $NQV < 0.8$, which are called low priority mobile nodes. Figure 5.9 shows the throughput for high priority mobile nodes. It can be observed from the figure that as the number of low priority mobile nodes increases, the throughput degrades severely for high priority mobile nodes in case of RSSI based handover. For the proposed QoS based handover scheme, the throughput for high priority nodes are maintained as the number of low priority nodes increases in the network. The small drop in throughput for the proposed scheme is due to high contention in the network as total number of node increases.

Similar result can be observed for end-to-end delay as shown in Figure 5.10. For RSSI based handover, the end-to-end delay for high priority mobile nodes increases as number of low priority mobile node increases. For the proposed scheme, the end-to-end delay is maintained steadily for high priority traffic. Similar to the previous case, the little increase of delay for the proposed scheme is due to high contention in the network as total number of node increases.

In the proposed scheme, bandwidth reservation is based on NQV value of a mobile node. Thus the QoS observed by a mobile node is proportional to its NQV value. The proportional fairness index for the network is calculated using equation (5.6). Figure 5.11 shows the proportional fairness index for overall network. For RSSI based handover, as number of mobile nodes increases, the value of proportional fairness index drops significantly. For the proposed QoS based handover, proportional fairness index is maintained steadily as number of mobile nodes increases. With 100 numbers of node there is almost 28% increase in proportional fairness index in the proposed scheme.

5.3 Summary

This chapter proposes a QoS based vertical handover scheme between UMTS and IEEE 802.11 WLAN network based on intermediate switching framework. Per-node bandwidth reservation is proposed based on the economic subscription of the mobile nodes with the service provider. The proposed per-node bandwidth reservation is used to reserve bandwidth for a possible handover. Further, if the QoS for a mobile node degrades because of network variability, the handover decision is taken cooperatively by the mobile node and its current point of attachment to find out a better network. The effectiveness of the proposed scheme is analyzed using simulation results.

Chapter 6

Conclusion and Future Works

This dissertation has put forward three important and significant contributions towards seamless vertical handover between UMTS and IEEE 802.11 networks. We studied the problem of seamless vertical handover and overall, our work provided a comprehensive foundation in terms of an architectural framework, set of algorithms, and a simulated system for validating the proposed framework. We summarize our works in Section 6.1, and discuss future directions in Section 6.2

6.1 Thesis Summary

The first contribution of this thesis proposes a new loosely-coupled architecture for seamlessly integrating UMTS and WLAN networks called Intermediate Switching Network(ISN), which is based on MPLS and MP-BGP for optimal packet delivery using the shortest path routing algorithm. The ISN is integrated with the UMTS network at the GGSN-3G and with the IEEE 802.11 network at the AP. The use of the switching network avoids sub-optimal routing (triangular routing + bidirectional tunneling) and also allows the user to experience higher data rates when in the IEEE 802.11 network. Switching of data traffic based on MPLS and MP-BGP reduces the handoff delay. The changes required due to the integration of ISN has to be made only at the GGSN-3G in the UMTS network and at the AP in the IEEE 802.11 networks. This ISN based integration framework is validated using simulations which shows that it handles UDP data traffic well and supports the norms of multimedia data service requirements. Thus this MPLS and MP-BGP based architecture provides us with an efficient technique for handoff between heterogeneous networks and allows the user with the opportunity to experience better data rates as compared with Mobile IP based systems.

The second contribution of this thesis evaluates the performance of TCP traffic using ISN-based framework. It has been observed that unnecessary congestion control is triggered during handover which degrades TCP performance. It also suffers from out-of-order delivery of packets, spurious timeouts leading to unnecessary packet retransmission, packet loss and network under/over utilization due to drastic changes in the link characteristics of heterogeneous networks. An improved TCP variant, called ISN-TCP-PLUS has been proposed to overcome the problems associated with TCP traffics over the ISN framework. In ISN-TCP-PLUS, TCP connection maintenance during handover is handled using a cross-layer interaction between the transport and the network layer, and estimation of updated TCP parameters after handover. By filtering out the duplicate ACKs (DACKs) and calculating the RTT of the new network on the fly, ISN-TCP-PLUS improves the performance of the TCP significantly during handover. The proposed scheme uses an approximation in CWnd calculation, similar to the approaches used for the equation based TCP congestion control [85,86]. This scheme avoids triggering unnecessary TCP congestion control mechanism, and therefore significantly improves TCP performance over the new vertical handover framework. The performance of the ISN-TCP-PLUS has been analyzed using simulation results.

The third contribution of this thesis moves into the concept of Quality of service to ensure ‘always best connectivity’ which becomes an essential part of the network in concern and also to the users. To ensure the increasing need of users to stay always best connected with an economically subscribed high data rates irrespective of their mobility and geographic location is a critical issue. A QoS based vertical handover scheme between UMTS and IEEE 802.11 WLAN network based on the ISN based framework has been proposed. A per-node bandwidth reservation is designed based on the economic subscription of the mobile nodes with the service provider. The proposed per-node bandwidth reservation is used to reserve bandwidth for a possible handover. Further, if the QoS for a mobile node degrades because of network variability, the handover decision is taken cooperatively by the mobile node and its current point of attachment to find out a better network. As the UMTS network is available all the time, so whenever a mobile node is attached with a WLAN, it is always preferable to handover to another WLAN, if available as compared to handover to the UMTS network. This is because sudden performance degradation can be observed if the mobile node is handed over to the UMTS network from WLAN network. Further, existing connections are preferred over new connections. The effectiveness of the proposed scheme is also analyzed using simulation results.

6.2 Future Works

The utilities for the ISN based vertical handover framework can be further enhanced with several aspects, which are the possible extensions of this thesis. Some of these extensions are as follows.

- This thesis assumes that both the UMTS and the IEEE 802.11 networks are under a single service provider, and therefore does not deal with the security and authentication aspects of the vertical handover framework. In a real scenario, different networks can be under different service providers, and therefore the authentication and the security mechanisms are required to be integrated with the ISN framework. In the present world, interoperability among the networks from different service providers requires specific policy designing and implementations that can be incorporated with the authentication, authorization and accounting (AAA) server, which is one of the future works in this direction.

- In this thesis, we have studied the effects of TCP traffic during vertical handover between UMTS and WLAN networks and analysed the problems of TCP using various handoff procedures and proposed new algorithms to enhance TCP performance. Moving to a faster network with higher bandwidth after handover is challenging to TCP. TCP needs to be more aggressive to be able to fully utilize the available data rates and this cannot be done based on only the information about the current link characteirstics. In future, we need to study how TCP can combine may be some probe mechanism to find out about the new network path and the notifications about the link characteristics so that it can safely and more quickly converge to the new network capacity and new RTT. In addition, it will be intersting to be able to analyse TCP in a real world accesss network to evaluate our proposed algorithms. Another direction for further work can be to develop an analytical model for TCP flows during vertical handover.

- The future cellular connectivity for the 4G networks relies on 'Long term Evolution' (LTE) networks, that supports different tiers of connectivities, through the concepts of macro, femto and pico cells. The vertical handover between LTE and WiFi is more complex as a result of different levels of granularity supported by macro, femto and pico cellular networks. Femto-WiFi integration has been already being studied in the literature [96, 97]. The concept of ISN provides a good base for integrating different levels of granularities supported by the LTE with the WiFi networks, that can be a good area for the future research.

- Like the cellular networks, WiFi is also showing a big lap to support high speed access technologies through IEEE 802.11n and IEEE 802.11ac standards. These physical access technologies support very high data rates (IEEE 802.11n supports upto 600 Mbps whereas IEEE 802.11ac supports gigabit connections). One of the key technologies used in IEEE 802.11ac/n is the channel bonding, where multiple channels are accumulated to support a wider channels with higher data rates. For example, IEEE 802.11n supports the integration of two 20 MHz channels to support communication through a 40 MHz channel. Though wider channels theoretically supports high data rates, they are more prone to channel errors. As a consequence, several trade-off exists while integrating LTE with Gigabit WiFi through the ISN framework, that should be looked at for further researches in this domain.

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Publications Related to Thesis

Published:

Journals

1. **Maushumi Barooah**, Sandip Chakraborty, Sukumar nandi and Dhananjay U. Kotwal, “An Architectural Framework for Seamless Handoff between IEEE 802.11 and UMTS Network”, ACM/Springer Journal of Wireless Networks, Volume 19, Issue 4, May 2013, Page 411-429
2. Aditya Yadav, **Maushumi Barooah**, Sandip Chakraborty, Sukumar Nandi, Sanjay Ahuja, “Evaluation of the End-to-End TCP Performance for Vertical Handover using Intermediate Switching Network”, International Journal of Communication Networks and Distributed System, Inderscience (In Press)
3. Aditya Yadav, **Maushumi Barooah**, Sandip Chakraborty, Sukumar Nandi, “Vertical Handover over Intermediate Switching Framework: Assuring Service Quality for Mobile Users”, Wireless Personal Communications, Springer (In Press)

Conference Proceedings

1. **Maushumi Barooah**, Sanjay Ahuja, Sandip Chakraborty and Sukumar Nandi, “TCP Performance for WLAN-GPRS Handover in an Intermediate Switching Network based Framework”, in proceedings of the 5th IEEE International Conference on Advanced Networks and Telecommunication System, December 18-21, 2011. (IEEE Press).
2. Dhananjay Kotwal, **Maushumi Barooah** and Sukumar Nandi, “Seamless Handoff between IEEE 802.11 and GPRS Networks”, in proceedings of the 6th International Conference on Distributed Computing & Internet Technology, February 2010 (LNCS).

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